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Aerospace Corp, Los Angeles, Calif.

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CONTROLLING SO$_2$ EMISSIONS FROM COAL-FIRED STEAM-ELECTRIC GENERATORS: SOLID WASTE IMPACT

(Volume II. Technical Discussion)

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Flue Gases	Power Generation	Solid Wastes	21B	10A
Desulfurization	Scrubbers		07A,07D	
Wastes	Coal Preparation			08I
Coal	Washing		08G,21D	13H

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(Volume II. Technical Discussion)

by

P. P. Leo and J. Rossoff

The Aerospace Corporation
P.O. Box 92957
Los Angeles, California 90009

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EPA Project Officer: Julian W. Jones

Industrial Environmental Research Laboratory
Office of Energy, Minerals and Industry
Research Triangle Park, N.C. 27711

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P. P. Leo

P. P. Leo
Office of Stationary Systems
Environment and Energy
Conservation Division

J. Rossoff

J. Rossoff, Director
Office of Stationary Systems
Environment and Energy
Conservation Division

Approved:

T. Iura, General Manager
Environment and Energy
Conservation Division

ABSTRACT

The Environmental Protection Agency (EPA) Office of Air Quality Planning and Standards (OAQPS), Durham, North Carolina, is reviewing the New Source Performance Standards (NSPS) for sulfur dioxide (SO_2) emissions from coal-fired steam electric generators. A number of control strategies are defined, e.g., increased scrubbing efficiency and coal washing, for achieving several levels of SO_2 emission control with emphasis on levels more stringent than the current NSPS. In support of that review, this study is aimed at providing an assessment of technological, economic, and environmental impacts, projected to 1998, of the increased solid wastes resulting from the application of the various more-stringent controls as well as the current NSPS.

The study considers three alternative strategies (1.2 lb $SO_2/10^6$ Btu, 90 percent SO_2 removal, and 0.5 lb $SO_2/10^6$ Btu), three plant sizes (1000, 500, and 25 MW), and five flue gas desulfurization (FGD) systems (lime, limestone, double alkali, magnesium oxide, and Wellman-Lord). Typical eastern and western coals containing 3.5 percent and 0.8 percent sulfur, respectively, as well as coal washing are included. The range of variability of sulfur content in coals, while not considered explicitly, was assumed to result in the typical values defined when considered in a national aggregate. Additionally, the ground rules include the following: (a) the interval for the nationwide survey (1978 through 1998), (b) the new plant installed capacity during that interval (Federal Power Commission projection), (c) the establishment of 1980 as the effective date for the more stringent standards for purposes of this study, and (d) the quantity of western coal burned during the 1980-1998 period to be 45 percent of the total burned on a nationwide basis.

The application of more stringent standards would possibly affect the percentage of western coal burned. Because predictions of the impacts of these standards on western coal usage were not available, the quantities and volumes of wastes that would be produced nationally as a result of burning different fractions of western coal were computed on a parametric basis.

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CONTENTS

ACKNOWLEDGMENTS iii
ABSTRACT v
CONVERSION TABLE xvii
I. INTRODUCTION 1
II. SUMMARY 3
    2.1 Quantification of Solid Wastes 11
        2.1.1 Effect of 0.5 lb $SO_2/10^6$ Btu Standard 11
        2.1.2 Effect of 90-Percent Scrubbing 11
        2.1.3 Effect of Coal Washing 11
        2.1.4 Plant Size Effects on Waste Quantities 12
        2.1.5 Effect of Coal Sulfur Content 12
        2.1.6 Effect of Various Scrubbing Processes ... 12
        2.1.7 Nationwide Projections to 1998 13
    2.2 Characterization of Untreated Wastes 17
        2.2.1 Effect of Scrubbing Process Variables on Sludge Chemistry 17
        2.2.2 Trace Element Content 17
        2.2.3 Physical Properties 19
        2.2.4 Chemical Properties 19
    2.3 Potential Environmental Impact 20
    2.4 Waste Disposal 20
    2.5 Utilization 20
    2.6 Economics 21

Preceding page blank

cont from pg vii

CONTENTS (Continued)

III. QUANTIFICATION OF SOLID WASTES 23

- 3.1 Basis for the Study 23
  - 3.1.1 Plant Installation Basis 23
  - 3.1.2 Nationwide Basis 32
- 3.2 Implications of Current and Stricter NSPS Emissions Regulations on SO_2 Removal 39
  - 3.2.1 Current Federal Standards: 1.2 lb $SO_2/10^6$ Btu 39
  - 3.2.2 Ninety-Percent SO_2 Removal 43
  - 3.2.3 More-Stringent Emissions Standard: 0.5 lb $SO_2/10^6$ Btu 44
- 3.3 Implications of NSPS Regulations on Quantities of Waste Produced 44
  - 3.3.1 Nonregenerable Scrubbing Processes 44
  - 3.3.2 Regenerable Processes 46
- 3.4 Effect of Plant Size on Quantities of Waste Produced 46
- 3.5 Effects of the Scrubbing Process on Quantities of Waste Produced 46
  - 3.5.1 Nonregenerable Processes 49
  - 3.5.2 Regenerable Processes 49
- 3.6 Effects of Coal Sulfur on Quantities of Waste Produced 49
- 3.7 Effects of Coal Washing on Quantities of Waste Produced 53
- 3.8 Nationwide Effects 61
  - 3.8.1 Quantities Produced 61
  - 3.8.2 Land Requirements 65

cont p. ix

cont from pg viii

CONTENTS (Continued)

IV. CHARACTERIZATION OF FLUE GAS DESULFURIZATION WASTES 69

- 4.1 Effects of Control System Process 70
  - 4.1.1 Design Parameters 70
  - 4.1.2 Operating Parameters 70
- 4.2 Chemical Characteristics 72
  - 4.2.1 Major Chemical Constituents 78
  - 4.2.2 Minor Chemical Constituents 78
  - 4.2.3 Leaching Characteristics 81
- 4.3 Physical Characteristics 83
  - 4.3.1 Water Retention and Bulk Density 83
  - 4.3.2 Compressive and Load Bearing Strength 86
  - 4.3.3 Permeability 89
  - 4.3.4 Viscosity 90
  - 4.3.5 Compaction 90
  - 4.3.6 Porosity 92
  - 4.3.7 Regenerable Processes 92
- 4.4 Potential Environmental Impacts 95
  - 4.4.1 Water Pollution 96
    - 4.4.1.1 Pollution by Runoff 96
    - 4.4.1.2 Pollution by Groundwater 97
    - 4.4.1.3 Impact Assessment 100
  - 4.4.2 Ability to Support Vegetation 101

V. ASSESSMENT OF WASTE DISPOSAL AND UTILIZATION TECHNOLOGY 103

- 5.1 Environmental Impacts of Disposal Processes and Practices 103
  - 5.1.1 Ponding 106
  - 5.1.2 Chemical Treatment 107

con't from pg ix

CONTENTS (Continued)

5.1.3 Mine Disposal 108
5.1.4 Ocean Disposal 109
5.1.5 Conversion to Gypsum 110
5.1.6 Conversion to Sulfuric Acid or Sulfur 111
5.1.7 Use as Synthetic Aggregate 113
5.2 Economic Evaluation of Disposal Processes and Practices 113
5.2.1 Economics Related to Power Plant Operating Conditions 113
5.2.2 Economics of Disposal Processes 114
5.2.2.1 Ponding of Untreated Wastes 114
5.2.2.2 Chemical Treatment and Disposal 117
5.2.2.3 Mine Disposal 118
5.2.2.4 Ocean Disposal 119
5.2.2.5 Cost Comparison 121
5.2.3 Economics of Utilization Processes 121
5.2.3.1 Conversion to Gypsum 122
5.2.3.2 Conversion to Sulfur or Sulfuric Acid 123
5.2.4 Nationwide Cost Estimates for Various Disposal Processes 123
REFERENCES 127

APPENDIXES

A. EMISSIONS AND SOLID WASTE QUANTITIES FOR ALTERNATIVE CONTROL SYSTEM MODEL PLANTS 131
B. NATIONWIDE SUMMARY OF PREDICTED TOTAL WASTES PRODUCED BY NON-REGENERABLE SCRUBBING PROCESSES 149

CONTENTS (Continued)

C. PROJECTED NATIONWIDE QUANTITIES OF SULFURIC ACID OR ELEMENTAL SULFUR PRODUCED FROM REGENERABLE SYSTEMS 191

D. CHEMICAL CHARACTERIZATION DATA 193

TABLES

1. Alternative Control Systems for Model Plants 2

2. Summary of Solid Wastes Produced 4

3. Quantity and Volume of Nonregenerable SO_2 Scrubber Wastes Produced in 1998 by New Coal-Burning Plants Constructed Between 1978 and 1998 14

4. Volume of Nonregenerable SO_2 Scrubber Wastes Produced in a 30-Year Generating Plant Lifetime 16

5. Range of Concentrations of Chemical Constituents in FGD Sludges from Lime, Limestone, and Double Alkali Systems 18

6. Alternative Control Systems for Model Plants 24

7. Coal Characteristics Used in Study 25

8. Cross Reference of Alternative Standards and Model Plants With Study Case Numbers 29

9. Format for Lime and Limestone and Double Alkali Scrubbers 33

10. Format for Magnesium Oxide and Wellman-Lord Processes . . 34

11. Basic Steam Generating Plant Characteristics Used in Study 36

12. Basic Scrubber and FGD Process Characteristics Used in Study 36

13. Conditions to Meet Various Performance Standards 41

14. Waste Quantities and Disposal Area for a 500-MW Plant With Limestone Scrubbing 45

TABLES (Continued)

15. Waste Quantities and Useable By-Products Produced from a 500-MW Plant Applying Regenerable SO_2 Removal Processes 47

16. Waste Quantities and Compositions from Five Flue Gas Desulfurization Processes Meeting Current and Alternative NSPS Standards 50

17. The Effects of Sulfur Content on the Waste and Disposal Area Required 52

18. Effect of High- and Low-Btu Western Coal on Waste Generated and Disposal Area Required 54

19. Comparison of the Emissions and Wastes Produced from Burning Low-Sulfur Coal 55

20. Effects of Coal Washing 58

21. Baseline Conditions for Nationwide Quantification of Scrubber Waste Disposal 62

22. Scrubber and Coal Washing Conditions Used in the Nationwide Waste Inventory 63

23. Computed Annual Quantities of Sulfuric Acid or Elemental Sulfur from Nonregenerable Scrubber Systems 66

24. Flue Gas Desulfurization Sampled as Data Base 71

25. Relative Change in Concentration of Constituents in the Scrubber Circuit Liquor: Limestone Process 75

26. Change of Concentrations of Chemical Constituents in FGD Sludges from Lime, Limestone, and Double-Alkali Systems 76

27. Net Change in Scrubber Liquor Composition of Major, Minor, and Trace Constituents Between Initial and Final Stages in Scrubber System 77

TABLES (Continued)

28. Phase Composition of FGD Waste Solids in Weight Percent . . . 79

29. Water Retention and Bulk Density Characteristics 85

30. Partition of Elements by Their Tendencies for Distribution in Coal Combustion Residues 94

31. Input Data for Study Cases 99

32. Status of Magnesium Oxide Scrubbing Plants 112

33. Power-Rating-Size Cost Adjustment Factors 114

34. Reference Conditions for Cost Estimates 115

35. Estimated Costs for Ponding Untreated Wastes With Flexible 20-mil PVC Liner 116

36. Estimated Costs for Disposal of Untreated FGD Waste in Ponds with Indigenous Clay Soil 117

37. Estimated Costs for Chemical Treatment and Disposal 118

38. Estimated Costs for Disposal of Untreated FGD Sludge in On-Site Surface and Underground Mines 119

39. Estimated Costs for On-Shelf Ocean Disposal of Treated FGD Wastes 120

40. Disposal Cost Comparisons 121

41. Typical Quantities of Waste and By-Products Produced from SO_2 Scrubber Systems for 90 Percent SO_2 Removal 122

42. Estimated Costs for Forced Oxidation of Fly-Ash-Free FGD Wastes to Gypsum 123

43. Regenerable Process Cost Data 124

44. Disposal Costs for Various Disposal Methods: Nationwide Totals 125

FIGURES

1. Effect of Eastern Coal Use on the Fraction of Waste Quantities, Including Ash, Produced Nationally 15

2. Lime and Limestone Scrubbing: Block Diagram 26

3. Double Alkali Scrubbing: Block Diagram 27

4. Magnesium Oxide and Wellman-Lord Processes: Generalized Block Diagram 28

5. Generalized Diagram and Algorithms for Coal Washing Process 35

6. Annual and Cumulative Installed Coal-Burning Plant Capacity 37

7. Effect of Eastern Coal Use on Nationwide Waste Quantities . . . 38

8. Flow Diagram Describing Computation of Nationwide SO_2 Scrubber By-Products 40

9. Nomograph: Relationship Between Coal Properties and SO_2 Emissions, With and Without SO_2 Scrubbing 42

10. Effect of Sulfur Content on Emissions for 90-Percent SO_2 Removal 43

11. Effect of Power Plant Size and Equivalent Capacities on the Amount of Solid Wastes Produced (Includes Ash). 48

12. Solid Waste, Including Ash, and Useable By-Products (Nonregenerable and Regenerable Systems) 51

13. Quantities of Waste, Including Ash, Produced by New Plants for Alternative Standards 56

14. Relative Quantities of Waste, Including Ash, Produced by New Plants as a Function of Coal Sulfur Content and Alternative NSPS Emission Standards 57

15. Relative Quantities of Solid Wastes from Scrubbing and Coal Washing from a 500-MW Plant Burning 7-Percent Sulfur Coal to Meet 0.5 lb $SO_2/10^6$ Btu Emissions Standard 60

FIGURES (Continued)

16. Total Annual Waste Quantities, Including Ash, Produced Nationwide by New Plants Coming on Line Beginning in 1978 64

17. Total Acreage Required Annually for Disposal of Scrubber Wastes, Including Ash, Produced Nationwide by New Plants Coming on Line Beginning in 1978 67

18. Average Trace Element Content of Sludge Solids 73

19. Average Trace Element Content of Sludge Liquor 74

20. Analysis of Leachate from TVA Shawnee Limestone Sludge: Aerobic Conditions 82

21. Analysis of Leachate from Duquesne Phillips Sludge: Aerobic Conditions 82

22. Compression Strength of Sludges and Sludge/Fly Ash Mixtures as a Function of Solids Content 87

23. Effect of Water Removal by Underdrainage on Load-Bearing Strength of Lime Sludges 88

24. Viscosity of Desulfurization Sludges 91

25. Mass Loading of TDS to Subsoil for Various Disposal Modes of Treated and Untreated FGD Wastes 98

CONVERSION TABLE

British	Metric
1 inch	2.54 centimeters
1 foot	0.3048 meter
1 mile	1.609 kilometers
1 square foot	9,290 square centimeters
1 acre	4,047 square meters
1 cubic foot	28,316 cubic centimeters
1 gallon	3.785 liters
1 cubic yard	0.7646 cubic meter
1 pound	0.454 kilogram
1 ton (short)	0.9072 metric ton
1 pound per square inch	0.0703 kilogram per square centimeter
1 pound per cubic foot	0.01602 gram per cubic centimeter
1 ton per square foot	9,765 kilograms per square meter
1 part per million	1 milligram per liter (equivalent)
1 British thermal unit (Btu)	252 calories
1 pound per million Btu	0.43 grams per million joules; 1.80 grams per million calories
1 Btu per pound	2.324 joules per gram; 0.555 calories per gram

SECTION 1

INTRODUCTION

The Environmental Protection Agency (EPA) Office of Air Quality Planning and Standards (OAQPS), Durham, North Carolina, is reviewing the New Source Performance Standards (NSPS) for sulfur dioxide (SO_2) emissions from coal-fired steam electric generators. A number of control strategies have been defined, e.g., increased scrubbing efficiency and coal washing, for achieving several levels of SO_2 emission control with emphasis on levels more stringent than the current NSPS. In support of that review, this study is aimed at providing an assessment of technological, economic, and environmental impacts, projected to 1998, of the increased solid wastes resulting from the application of the various more-stringent controls as well as the current NSPS.

The study considered three alternative strategies (1.2 lb $SO_2/10^6$ Btu, 90 percent SO_2 removal, and 0.5 lb $SO_2/10^6$ Btu), three plant sizes (1000, 500, and 25 MW), and five flue gas desulfurization (FGD) systems (lime, limestone, double alkali, magnesium oxide, and Wellman-Lord). Typical eastern and western coals, as well as coal washing, were included. Initially, the various study cases totalled 67; they were subsequently increased to 93 to improve visibility into the impact of the various alternatives. The study cases are summarized in Table 1. Additional groundrules and guidelines were developed in conjunction with the technical monitor during the course of the study (1, 2). These are also outlined in Table 1 and include the following: (a) the interval for the nationwide survey (1978 through 1998), (b) the new plant installed capacity during that interval (Federal Power Commission projection), (c) the establishment of 1980 as the effective date for the more stringent standards for purposes of this study, and (d) the quantity of western coal burned during the 1980-1998 period to be 45 percent of the total burned on a nationwide basis.

The application of more stringent standards would possibly affect the percentage of western coal burned. Because predictions of the impacts of these standards on western coal usage were not available, quantities and volumes of wastes that would be produced nationally as a result of burning different fractions of western coal were computed on a parametric basis.

TABLE 1. ALTERNATIVE CONTROL SYSTEMS FOR MODEL PLANTS[a, b]

Plant Sizes To Be Considered, MW	FGD Systems To Be Considered	Alternative Standards and Model Plant Systems
25; 500; 1000	5[c]	1. The existing NSPS of 1.2 lb $SO_2/10^6$ Btu heat input. a. 90-percent SO_2 removal on a plant burning a typical coal of 3.5 percent sulfur.
25; 500; 1000	Lime/limestone	b. A plant burning a typical 7-percent sulfur coal with 90-percent SO_2 removal by FGD.
25; 500	---	c. Low-sulfur coal without FGD for a typical eastern plant.
25; 500	---	d. Low-sulfur coal without FGD for a typical western plant.
500	Lime/limestone	e. 40-percent sulfur removal by coal washing of a 3.5-percent-sulfur coal followed by 65-percent SO_2 removal by FGD.
25; 500; 1000	5[c]	2. a. 90-percent SO_2 removal by FGD on a typical coal of 3.5 percent sulfur and a typical coal of 7 percent sulfur.
25; 500	Lime/limestone	b. 90-percent SO_2 removal by FGD on a plant burning a typical western coal of 0.8 percent sulfur (western plant).
25; 500	Lime-limestone	3. 0.5 lb SO_2 emissions/10^6 Btu heat input. a. 70- to 75-percent SO_2 removal by FGD on a 0.8-percent-sulfur western coal (western plant).
25; 500	Lime/limestone	b.1 40-percent sulfur removal by coal washing of a 3.5-percent-sulfur coal and 85-percent removal by FGD.
500	Lime/limestone	b.2 40-percent sulfur removal by coal washing of a 7-percent-sulfur coal and 95-percent removal by FGD.

[a] Reference 3.

[b] Per References 1 and 2.
- Study encompasses 1978-1998 period.
- More stringent standards to apply in 1980.
- New plant installed capacity per Federal Power Commission projections.
- For 1980 and thereafter, 45 percent of the coal burned nationally is western, low sulfur.

[c] The five systems to be considered are lime, limestone, magnesium oxide, double alkali, and Wellman-Lord.

SECTION II

SUMMARY

Solid wastes resulting from the scrubbing of flue gases from coal-fired steam-generating utility boilers were quantified for 1000-, 500-, and 25-MW units for nonregenerable (lime, limestone, and double alkali) and regenerable (magnesium oxide and Wellman-Lord) processes. Typical eastern and western coals were included in the study. A number of control strategies were included, such as increased scrubbing efficiency and coal washing, to achieve several levels of emissions more stringent than the current New Source Performance Standards. The 93 cases studied and the resultant waste quantities and volumes are tabulated in Table 2.

Land requirements and technological, economic, and environmental impacts were projected to 1998, with the application of the more stringent controls in 1980.

Physical and chemical characteristics of the wastes were identified with respect to the potential pollution of water supplies, resulting from disposal of the wastes.

The applicability and effectiveness of the various control strategies in conjunction with existing disposal and utilization techniques to minimize environmental impacts were assessed. The status of the technological developments for disposal and utilization methods are also discussed.

The findings developed during the study are in the categories of

- Quantification of solid wastes
- Characterization of untreated wastes
- Environmental impact
- Waste disposal
- Utilization
- Economics

and are summarized below.

TABLE 2. SUMMARY OF SOLID WASTES PRODUCED[a]

Case No.	Coal			MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-Products, Dry, tons × 10^3/yr			Acre-Feet Required for Disposal, Annual
	% S	Btu/lb	% Ash							Ash	Sulfur Sludge	Total	
1	3.5	12,000	14	1000	Lime	90	0	80	1.2	222	210	432	448
2	3.5	12,000	14	500	Lime	90	0	80	1.2	115	108	223	232
3	3.5	12,000	14	25	Lime	90	0	80	1.2	6.4	6.1	12.5	13
4	3.5	12,000	14	1000	Limestone	80	0	80	1.2	222	229	451	468
5	3.5	12,000	14	500	Limestone	80	0	80	1.2	115	118	233	242
6	3.5	12,000	14	25	Limestone	80	0	80	1.2	6.4	6.7	13.1	14
7	3.5	12,000	14	1000	Na_2CO_3[b]	95[c]	0	80	1.2	222	206	428	444
8	3.5	12,000	14	500	Na_2CO_3[b]	95[c]	0	80	1.2	115	107	222	230
9	3.5	12,000	14	25	Na_2CO_3[b]	95[c]	0	80	1.2	6.4	6.0	12.4	13
10	3.5	12,000	14	1000	MgO[d]	5[f]	0	80	1.2	222	129[e]	42.2[e]	233
11	3.5	12,000	14	500	MgO[d]	5[f]	0	80	1.2	115	66.9[e]	21.8[e]	121
12	3.5	12,000	14	25	MgO[d]	5[f]	0	80	1.2	6.4	3.75[e]	1.22[e]	7

[a] Based on an average operating load factor of 50% (4380 hr/yr)

[b] Double-alkali process

[c] Regenerant (lime) utilization

[d] Magnesium-oxide process

[e] Sulfuric acid or sulfur produced, respectively

[f] Absorbent make-up

(continued)

TABLE 2. (Continued)

Case No.	Coal			MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-Products, Dry, tons × 10^3/yr			Acre-Feet Required for Disposal, Annual
	% S	Btu/lb	% Ash							Ash	Sulfur Sludge	Total	
13	3.5	12,000	14	1000	Na_2SO_3[a]	5[c]	0	80	1.2	222	129[b]	42.2[b]	237
14	3.5	12,000	14	500	Na_2SO_3[a]	5[c]	0	80	1.2	115	66.9[b]	21.8[b]	122
15	3.5	12,000	14	25	Na_2SO_3[a]	5[c]	0	80	1.2	6.4	3.75[b]	1.22[b]	7
16	7.0	12,000	14	1000	Lime	90	0	90	1.2	222	472	694	719
17	7.0	12,000	14	500	Lime	90	0	90	1.2	115	244	359	372
18	7.0	12,000	14	25	Lime	90	0	90	1.2	6.4	13.7	20.1	21
19	7.0	12,000	14	1000	Limestone	80	0	90	1.2	222	515	737	764
20	7.0	12,000	14	500	Limestone	80	0	90	1.2	115	266	381	395
21	7.0	12,000	14	25	Limestone	80	0	90	1.2	6.4	15.0	21.4	22
22	0.8	13,500	6	500	None	N/A	0	None	1.2	43.8	N/A[d]	43.8	44
23	0.8	13,500	6	25	None	N/A	0	None	1.2	2.45	N/A	2.45	3
24	0.6	10,000	8	500	None	N/A	0	None	1.2	78.8	N/A	78.8	80
241	0.4	8,000	6	500	None	N/A	0	None	1.0	73.9	N/A	73.9	74

[a] Wellman-Lord process

[b] Sulfuric acid or sulfur produced, respectively

[c] Absorbent make-up

[d] Not applicable

(continued)

TABLE 2. (Continued)

Case No.	Coal			MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-Products, Dry, tons × 10^3/yr			Acre-Feet Required for Disposal, Annual
	% S	Btu/lb	% Ash							Ash	Sulfur Sludge	Total	
25	0.6	10,000	8	25	None	N/A	0	None	1.2	4.42	N/A[a]	4.42	5
251	0.4	8,000	6	25	None	N/A	0	None	1.0	4.14	N/A	4.14	4
26	3.5	12,000	14	500	Lime	90	40	65	1.1	69	48	117[b]	121[b]
27	3.5	12,000	14	500	Limestone	80	40	65	1.1	71	50	121[b]	126[b]
28	3.5	12,000	14	1000	Lime	90	0	90	0.6	222	236	458	475
29	3.5	12,000	14	500	Lime	90	0	90	0.6	115	122	237	246
30	3.5	12,000	14	25	Lime	90	0	90	0.6	6.4	6.9	13.3	14
31	3.5	12,000	14	1000	Limestone	80	0	90	0.6	222	258	480	497
32	3.5	12,000	14	500	Limestone	80	0	90	0.6	115	133	248	257
33	3.5	12,000	14	25	Limestone	80	0	90	0.6	6.4	7.5	13.9	14
34	3.5	12,000	14	1000	Na_2CO_3[c]	95[d]	0	90	0.6	222	232	454	470
35	3.5	12,000	14	500	Na_2CO_3[c]	95[d]	0	90	0.6	115	120	235	243
36	3.5	12,000	14	25	Na_2CO_3[c]	95[d]	0	90	0.6	6.4	6.8	13.2	14

[a] Not applicable

[b] Does not include coal-wash tailings: 4.09 × 10^4 tons/yr (dry) and 28 acre-ft

[c] Double-alkali process

[d] Regenerant (lime) utilization

(continued)

TABLE 2. (Continued)

Case No.	Coal			MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-products, Dry, tons × 10^3/yr			Acre-Feet Required for Disposal, Annual
	% S	Btu/lb	% Ash							Ash	Sulfur Sludge	Total	
37	3.5	12,000	14	1000	MgO[a]	5[c]	0	90	0.6	222	146[b]	47.5[b]	11
38	3.5	12,000	14	500	MgO[a]	5[c]	0	90	0.6	115	75.3[b]	24.6[b]	6
39	3.5	12,000	14	25	MgO[a]	5[c]	0	90	0.6	6.4	4.22[b]	1.38[b]	0.3
40	3.5	12,000	14	1000	Na_2SO_3	5[c]	0	90	0.6	222	146[b]	47.5[b]	11
41	3.5	12,000	14	500	Na_2SO_3	5[c]	0	90	0.6	115	75.3[b]	24.6[b]	6
42	3.5	12,000	14	25	Na_2SO_3	5[c]	0	90	0.6	6.4	4.22[b]	1.38[b]	0.3
43	7.0	12,000	14	1000	Lime	90	0	90	1.2	222	472	694	719
44	7.0	12,000	14	500	Lime	90	0	90	1.2	115	245	359	372
45	7.0	12,000	14	25	Lime	90	0	90	1.2	6.4	13.7	20.1	21
46	7.0	12,000	14	1000	Limestone	80	0	90	1.2	222	515	737	764
47	7.0	12,000	14	500	Limestone	80	0	90	1.2	115	266	381	395
48	7.0	12,000	14	25	Limestone	80	0	90	1.2	6.4	15.0	21.4	22
49	7.0	12,000	14	1000	Na_2CO_3[d]	95[e]	0	90	1.2	222	464	686	710
50	7.0	12,000	14	500	Na_2CO_3[d]	95[e]	0	90	1.2	115	240	355	367
51	7.0	12,000	14	25	Na_2CO_3[d]	95[e]	0	90	1.2	6.4	13.5	19.9	21

[a] Magnesium-oxide process

[b] Sulfuric acid or sulfur produced, respectively

[c] Absorbent make-up

[d] Double-alkali process

[e] Absorbent (lime) utilization

(continued)

TABLE 2. (Continued)

Case No.	Coal			MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/ 10^6 Btu	By-Products, Dry, tons × 10^3/yr			Acre-Feet Required for Disposal, Annual
	% S	Btu/lb	% Ash							Ash	Sulfur Sludge	Total	
52	7.0	12,000	14	1000	MgO[a]	5^c	0	90	1.2	222	291^b	95^b	22
53	7.0	12,000	14	500	MgO[a]	5^c	0	90	1.2	115	150^b	49.2^b	11
54	7.0	12,000	14	25	MgO[a]	5^c	0	90	1.2	6.4	8.43^b	2.75^b	1
55	7.0	12,000	14	1000	Na_2SO_3[d]	5^c	0	90	1.2	222	291^b	95^b	22
56	7.0	12,000	14	500	Na_2SO_3[d]	5^c	0	90	1.2	115	150^b	49.2^b	11
57	7.0	12,000	14	25	Na_2SO_3[d]	5^c	0	90	1.2	6.4	8.43^b	2.75^b	0.6
58	0.8	10,000	8	500	Lime	90	0	90	0.2	79	33	112	116
581	0.8	8,000	6	500	Lime	90	0	90	0.2	74	42	116	120
59	0.8	10,000	8	25	Lime	90	0	90	0.2	4.42	1.87	6.29	7
591	0.8	8,000	6	25	Lime	90	0	90	0.2	4.14	2.34	6.48	7
60	0.8	10,000	8	500	Limestone	80	0	90	0.2	78	37	115	120
601	0.8	8,000	6	500	Limestone	80	0	90	0.2	74	46	120	124
602	0.8	8,000	6	500	Limestone	80	0	40	1.2	74	20	94.2	98
603	0.8	10,000	8	500	Limestone	80	0	25	1.2	79	10	89	92
6001	3.5	12,000	14	200	Limestone	80	0	80	1.2	47	48	95.4	99

[a] Magnesium-oxide process

[b] Sulfuric acid or sulfur produced, respectively

[c] Absorbent make-up

[d] Wellman-Lord process

(continued)

TABLE 2. (Continued)

Case No.	Coal			MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-Products, Dry, tons × 10^3/yr			Acre-Feet Required for Disposal, Annual
	% S	Btu/lb	% Ash							Ash	Sulfur Sludge	Total	
61	0.8	10,000	8	25	Limestone	80	0	90	0.2	4.41	2.05	6.46	7
611	0.8	8,000	6	25	Limestone	80	0	90	0.2	4.14	2.56	6.70	7
62	0.8	10,000	8	500	Lime	90	0	70	0.5	79	26	105	109
621	0.8	8,000	6	500	Lime	90	0	75	0.5	74	35	109	113
63	0.8	10,000	8	25	Lime	90	0	70	0.5	4.41	1.46	5.87	6
631	0.8	8,000	6	25	Lime	90	0	75	0.5	4.14	1.95	6.09	6
64	0.8	10,000	8	500	Limestone	80	0	70	0.5	79	28	107	111
641	0.8	8,000	6	500	Limestone	80	0	75	0.5	74	38	112	116
65	0.8	10,000	8	25	Limestone	80	0	70	0.5	4.41	1.59	6.00	6
651	0.8	8,000	6	25	Limestone	80	0	75	0.5	4.14	2.13	6.27	7
66	3.5	12,000	14	500	Lime	90	40	85	0.5	69	63	132[a]	137[a]
661	3.5	12,000	14	500	Limestone	80	0	91.5	0.5	115	135	250	260
67	3.5	12,000	14	25	Lime	90	40	85	0.5	3.87	3.52	7.39[b]	8[b]
68	3.5	12,000	14	500	Limestone	80	40	85	0.5	69	69	138[a]	143[a]

[a] Does not include coal wash tailings: 4.09×10^4 tons/yr (dry) and 28 acre-ft

[b] Does not include coal wash tailings: 2.29×10^3 tons/yr (dry) and 1.5 acre-ft

(continued)

TABLE 2. (Continued)

Case No.	Coal			MW	Absorbent	Absorbent Utilized, %	% S Removed by Wash	% SO_2 Removed by Scrub	Emissions, lb SO_2/10^6 Btu	By-Products, Dry, tons × 10^3/yr			Acre-Feet Required for Disposal, Annual
	% S	Btu/lb	% Ash							Ash	Sulfur Sludge	Total	
69	3.5	12,000	14	25	Limestone	80	40	85	0.5	3.87	3.84	7.71[a]	8[a]
70	7.0	12,000	14	500	Lime	90	40	95	0.3	30	140	170[b]	176[b]
701	7.0	12,000	14	500	Lime	90	40	92.5	0.5	30	136	166[b]	172[b]
702	7.0	12,000	14	500	Limestone	80	0	96	0.5	115	284	399	414
71	7.0	12,000	14	500	Limestone	80	40	95	0.3	30	153	183[b]	190[b]
711	7.0	12,000	14	500	Limestone	80	40	92.5	0.5	30	149	179[b]	185[b]
712	7.0	12,000	14	500	Limestone	90	40	92.5	0.5	30	136	166[b]	172[b]
713	7.0	12,000	14	500	Limestone	80	30	93.5	0.5	51	180	231[c]	240[c]
714	7.0	12,000	14	500	Limestone	80	20	94.5	0.5	72	214	286[d]	296[d]
715	7.0	12,000	14	500	Limestone	80	40	92.0	0.5	50	148	198[e]	206[e]
716	7.0	12,000	14	500	Limestone	80	40	92.0	0.5	69	149	218[f]	226[f]

[a] Does not include coal wash tailings: 2.29 × 10^3 tons/yr (dry) and 1.5 acre-ft

[b] Does not include coal wash tailings: 8.58 × 10^4 tons/yr (dry) and 58 acre-ft

[c] Does not include coal wash tailings: 6.43 × 10^4 tons/yr (dry) and 43 acre-ft

[d] Does not include coal wash tailings: 4.28 × 10^4 tons/yr (dry) and 29 acre-ft

[e] Does not include coal wash tailings: 6.29 × 10^4 tons/yr (dry) and 42 acre-ft

[f] Does not include coal wash tailings: 4.09 × 10^4 tons/yr (dry) and 28 acre-ft

2.1 QUANTIFICATION OF SOLID WASTES

In response to groundrules defined by OAQPS relating to current and more stringent emission standards, sulfur content of coal, and steam generating plant sizes, the effects of the following conditions on the solid wastes produced were included:

- Effect of the 0.5 lb $SO_2/10^6$ Btu standard
- Effect of 90-percent scrubbing
- Coal washing
- Plant size effects
- Coal sulfur content
- Scrubbing processes
- Nationwide projections to 1998

It should be noted that, for the various study cases, the coal properties were considered constant. Therefore, the results represent typical values encompassing the range of variations for eastern and western coals.

2.1.1 Effect of 0.5 lb $SO_2/10^6$ Btu Standard

A performance standard of 0.5 lb $SO_2/10^6$ Btu heat input would necessitate the scrubbing of all coal burned.

The removal of SO_2 by scrubbing that meets a standard of 0.5 lb $SO_2/10^6$ Btu requires 91.5 percent SO_2 removal for the case of burning 3.5-percent-sulfur coal. For the same coal it results in approximately a 7-percent increase in solid wastes produced relative to meeting the current standard of 1.2 lb $SO_2/10^6$ Btu.

2.1.2 Effect of 90-Percent Scrubbing

Compared to the wastes that would be produced by meeting the current NSPS of 1.2 lb $SO_2/10^6$ Btu, using nonregenerative alkali slurries to remove 90 percent of the SO_2 from flue gases, would increase solid waste quantities by approximately 6 percent for the 3.5-percent-sulfur case.

2.1.3 Effect of Coal Washing

Coal washing that removes 40 percent of the sulfur, combined with 85-percent scrubbing of 3.5-percent-sulfur coal, meets the 0.5 lb

$SO_2/10^6$ Btu standard and reduces solid wastes at the power plant by approximately 45 percent relative to the current NSPS condition.

The coal wash tailings [pyrites (FeS_2) and ash] from a 3.5-percent sulfur coal is 15 percent of the dry solid wastes produced by a generating plant burning the same coal, unwashed, and scrubbing SO_2 to meet the current standard of 1.2 lb $SO_2/10^6$ Btu.

2.1.4 Plant Size Effects on Waste Quantities

For large boiler sizes, in the 200- to 1000-MW range, waste quantities produced are linear and proportional to size within 6 percent, the smaller unit being less efficient. In the 25- to 200-MW range, the variation increases to 16 percent for the 25-MW unit.

2.1.5 Effect of Coal Sulfur Content

For 90-percent SO_2 removal from flue gas from the burning of 3.5-percent-sulfur coal, 0.6 lb $SO_2/10^6$ is emitted. With a higher sulfur content, the SO_2 emissions increase proportionately and, at 7.0-percent sulfur, reach the current standard of 1.2 lb $SO_2/10^6$ Btu.

To meet a 0.5 lb $SO_2/10^6$ Btu standard with coals having sulfur content greater than 3.5 percent, SO_2 removal in excess of 90 percent is required, e.g., 96-percent removal is required for 7.0-percent-sulfur coal.

The waste quantities produced by scrubbing 0.8- and 7.0-percent-sulfur coal to meet any of the three standards (i.e., 1.2, 0.5, and 90 percent) are approximately 45 percent and 155 percent, respectively, of the quantities produced from 3.5-percent-sulfur coal.

For any standard considered, wastes produced from scrubbing of typical western coals within the Btu ranges of high (10,000 Btu/lb, 8 percent ash, 0.8 percent sulfur) to low (8000 Btu/lb, 6 percent ash, 0.8 percent sulfur), are within 5 percent of each other.

2.1.6 Effect of Various Scrubbing Processes

The quantities of generating-plant wastes produced from the limestone nonregenerable process are about 5 percent greater than the lime and double alkali because of the stoichiometry of the limestone system. The waste generated is directly related to the stoichiometry; therefore, the waste quantities from typical lime scrubbing and double-alkali systems using lime to regenerate the absorbent are virtually identical.

Since the generating plants produce the same amount of ash regardless of the scrubbing process, steam generating plants that employ regenerable scrubbing; i.e., magnesium oxide or Wellman-Lord processes, produce ash that must be disposed of. The total weight of waste (ash) to be disposed of from a regenerable plant is about one-half the waste (ash and sludge) from a plant using nonregenerable scrubbing. For example, if 50 percent of the SO_2 were scrubbed by a regenerable process (which produces sulfur or sulfuric acid) and 50 percent scrubbed nonregeneratively, the total wastes would be 75 percent of that which would be produced if all the SO_2 were scrubbed nonregeneratively. Also, regenerable systems produce liquid streams that require purging: the magnesium oxide process produces an effluent high in chloride ion concentration, and the Wellman-Lord, a stream containing Na_2SO_4.

2.1.7 Nationwide Projections to 1998

Applying a 90-percent SO_2 removal requirement to all new plants in 1980 will result in the production of approximately 173 million short tons (dry) of wastes in the year 1998 (Table 3). The actual quantities of untreated wastes that would require disposal are approximately double that quantity, assuming that they contain approximately 50-percent moisture. This results in a volume of 179,000 acre-feet (wet) produced in those plants in 1998. The estimate is based on the assumption that eastern (3.5 percent sulfur) coal will be burned in 55 percent of the new boiler installations and 45 percent will consume western coal (0.8 percent sulfur) (Table 1).

These values were computed on the basis that 45 percent of the coal burned on a nationwide basis is western coal(4). However, application of more stringent standards would possibly affect the percentage used. Since predictions of the impacts of these standards on western coal usage were not available, the waste quantities resulting from the use of discrete fractions of eastern coal were computed and are summarized in Figure 1. For example, if the amount of coal from eastern sources were increased from 55 to 70 percent (western coal use reduced from 45 to 30 percent), the tonnages of eastern waste would increase from 73 to 83 percent of the nationwide total for 90 percent SO_2 removal.

The wastes to be disposed of at the generating plants in the year 1998 to meet a 0.5 lb SO_2 standard are 118 million short tons (dry). This considers that the eastern coal (3.5 percent sulfur) comprises 55 percent of the total coal used nationally and is washed to remove 40 percent of its sulfur.

Comparable quantities, if the current NSPS were maintained in 1998, are 156 million short tons (dry). Volumes produced are proportional to those given above.

The volume in acre-feet of nonregenerable scrubber wastes, primarily ash, produced during a 30-year steam generating plant lifetime is shown in Table 4 for 1000-, 500-, and 25-MW plants burning eastern and western coal, and assuming that current and two alternative emission standards apply.

TABLE 3. QUANTITY AND VOLUME OF NONREGENERABLE SO_2 SCRUBBER WASTES PRODUCED IN 1998 BY NEW COAL-BURNING PLANTS CONSTRUCTED BETWEEN 1978 AND 1998[a]

NSPS Alternatives	Dry Waste Quantities[b, c, d] (short tons)	Total Wet Volume[e] (acre-ft)
		For Sludge Produced in 1998
90% SO_2 Removal	172.8×10^6	1.79×10^5
0.5 lb $SO_2/10^6$ Btu[f]	118.3×10^6	1.22×10^5
1.2 lb $SO_2/10^6$ Btu	156.2×10^6	1.62×10^5

[a] Data derived from Appendix B, Vol II.

[b] Quantities produced, based on:
500-MWe average plant size.
50-percent average operating load factor.
Limestone absorbent, 80% utilization.
Waste includes ash.
Eastern[c] coal burned: 55% of total.
Western[d] coal burned: 45% of total.

[c] Eastern coal: 3.5% S, 12,000 Btu/lb, 14% ash

[d] Western coal: 0.8% S, 8000 Btu/lb, 6% ash

[e] Based on sludge containing 50% solids.

[f] 40% of sulfur in eastern coal removed by washing prior to burning, 85% SO_2 from eastern plants removed by scrubbing, and 40% SO_2 from western plants removed by scrubbing.

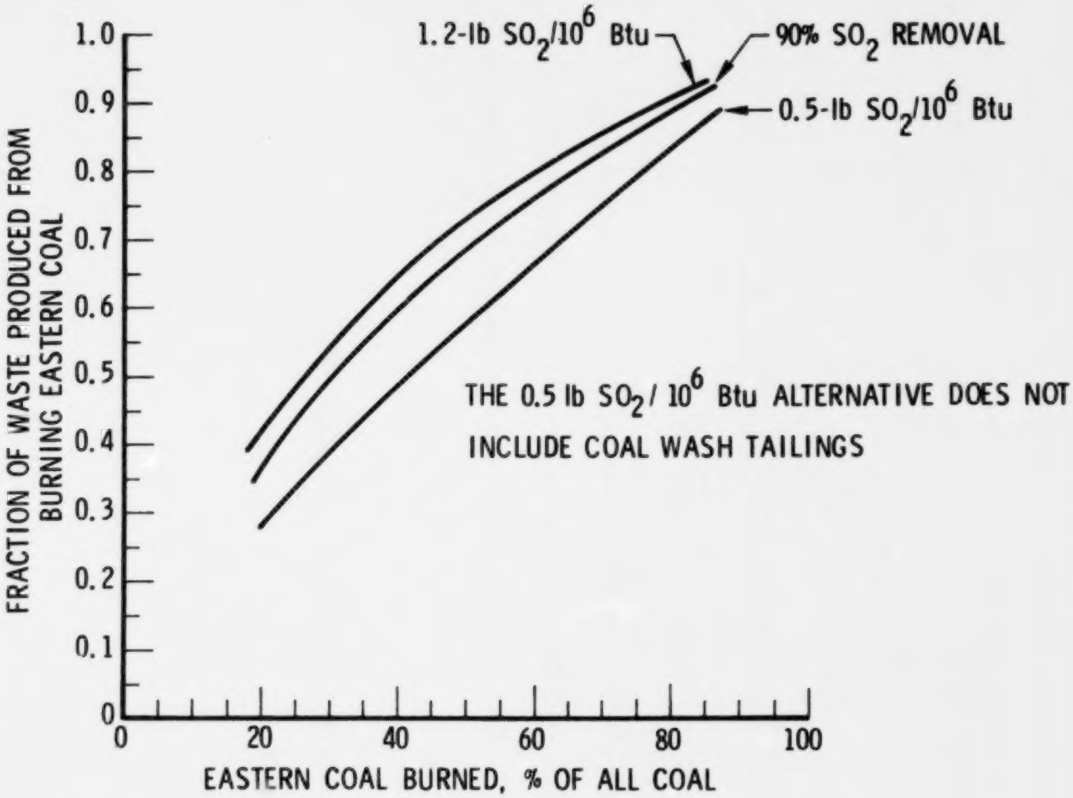


Figure 1. Effect of eastern coal use on the fraction of waste quantities, including ash, produced nationally by new plants

TABLE 4. VOLUME (ACRE-FEET) OF NONREGENERABLE SO_2 SCRUBBER WASTES PRODUCED IN A 30-YEAR[a] GENERATING PLANT LIFETIME

Plant Size, MW	Eastern Coal[b]				Western Coal[b]		
	NSPS Alternatives						
	1.2 lb SO_2 per 10^6 Btu[c]	90% SO_2 Removal[d]	0.5 lb SO_2 per 10^6 Btu[e]		1.2 lb SO_2 per 10^6 Btu[f]	90% SO_2 Removal[g]	0.5 lb SO_2 per 10^6 Btu[h]
			Sludge	Coal wash Tailings			
1000	14,030	14,920	NR	--	NR	NR	NR
500	7,260	7,720	4280	830	2930	3720	3480
25	405	430	240	45	NR	210	195

[a] 50-percent average operating load factor; limestone absorbent, 80% utilization; waste includes ash.

[b] Eastern coal: 3.5% S, 12,000 Btu/lb, 14% ash; Western coal: 0.8% S, 8000 Btu/lb, 6% ash.

[c] 80% SO_2 removal by scrubbing

[d] 0.6 lb $SO_2/10^6$ Btu

[e] 40% sulfur removal by coal washing, 85% SO_2 removal by scrubbing

[f] 40% SO_2 removal by scrubbing

[g] 0.2 lb $SO_2/10^6$ Btu

[h] 75% SO_2 removal by scrubbing

NR - Not required (see Table 3)

2.2 CHARACTERIZATION OF UNTREATED WASTES

The published data available on the chemical and physical characteristics of untreated sludges produced in eastern and western plants using lime, limestone, and double-alkali scrubber systems are provided in this report. The primary waste streams from plants using regenerable systems are fly ash, the properties of which are discussed briefly in Section 4.3.7, and purged liquid effluents, consideration of which were not within the scope of this report. Properties of wastes from nonregenerable systems which are discussed are: solids composition and concentrations in the liquor of major species and trace elements; pH; total dissolved solids; leaching characteristics; water retention; bulk density; compressive strength; permeability, viscosity; compaction; and porosity. All properties are widely variant depending on parameters such as types of: coal, absorbent, scrubber, scrubber operating parameters, and ash collection. The characteristics included in this report summary are given below.

2.2.1 Effect of Scrubbing Process Variables on Sludge Chemistry

Process variables affect the concentrations of soluble chemical species in system liquors through changes in process chemistry:

a. The concentration of major chemical species and trace elements in flue gas desulfurization (FGD) waste decreases as the sludge passes from the scrubber to the clarifier underflow for disposal. Concentrations of sludge constituents for disposal are given in Table 5.

b. The pH in the scrubber is responsible for trace elements leaching from fly ash; the pH of the system downstream of the scrubber does not affect the concentration of these trace elements in the scrubber liquor.

2.2.2 Trace Element Content

The trace element content in FGD sludge is a direct function of the combustion products of coal:

a. A direct correlation exists between the trace element content of coal and the trace element content in FGD wastes.

b. Fly ash represents the major source of trace elements in all but the most volatile elemental species (e.g., mercury and selenium) that are scrubbed from flue gases.

TABLE 5. RANGE OF CONCENTRATIONS OF CHEMICAL CONSTITUENTS IN FGD SLUDGES FROM LIME, LIMESTONE, AND DOUBLE-ALKALI SYSTEMS

Scrubber Constituent	Sludge Concentration Range[a]	
	Liquor, mg/ℓ (except pH)[b]	Solid, mg/kg[c]
Aluminum	0.03 - 2.0	- -
Arsenic	<0.004 - 1.8	0.6 - 52
Beryllium	<0.002 - 0.18	0.05 - 6
Cadmium	0.004 - 0.11	0.08 - 4
Calcium	180 - 2600	105,000 - 268,000
Chromium	0.015 - 0.5	10 - 250
Copper	<0.002 - 0.56	8 - 76
Lead	0.01 - 0.52	0.23 - 21
Magnesium	4.0 - 2750	- -
Mercury	0.0004 - 0.07	0.001 - 5
Potassium	5.9 - 100	- -
Selenium	< 0.0006 - 2.7	2 -17
Sodium	10.0 - 29,000	- - 48,000
Zinc	0.01 - 0.59	45 - 430
Chloride	420 - 33,000	- - 9,000
Fluoride	0.6 - 58	- -
Sulfate	600 - 35,000	35,000 - 473,000
Sulfite	0.9 - 3500	1600 - 302,000
Chemical oxygen demand	< 1 - 390	- -
Total dissolved solids	2800 - 92,500	- -
pH	4.3 - 12.7	- -

[a] Data derived from Appendix D, Vol II.

[b] Liquor analyses were conducted on 13 samples from seven power plants burning eastern or western coal and using lime, limestone, or double-alkali absorbents.

[c] Solids analyses were conducted on 6 samples from six power plants burning eastern or western coal and using lime, limestone, or double-alkali scrubbing processes.

2.2.3 Physical Properties

The behavior of FGD wastes in a disposal site is a function of the unique physical properties of the wastes:

a. The permeability coefficients of untreated FGD wastes are typically 10^{-4} cm/sec and of treated wastes are 10^{-5} cm/sec or less [based upon sample materials fixed by Chemfix, Dravo, and IU Conversion Systems (IUCS)].

b. Pumpability (< 20 poise) was found for untreated wastes having a solids content that ranged between 32 and 70 percent.

c. Bulk densities of untreated wastes as a function of dewatering techniques and material characteristics varied between 1.30 and 1.87 g/cc.

d. Compaction of untreated sludges dewatered to about 80 percent solids produced permanent displacement of 1 to 4 percent.

e. Treated wastes have unconfined compression strength greater than 1.8 tons per square foot (25 psi).

2.2.4 Chemical Properties

Lime and limestone FGD sludge liquors typically have approximately 10,000 mg/*l* total dissolved solids (TDS). Double-alkali scrubber sludge liquors from unwashed filter cake leave a much higher TDS, in excess of 50,000 ppm. When the cake is washed with water to remove soluble sodium salts, the TDS concentration tends to approach that of the lime and limestone sludge liquors. Trace elements lie typically between 0.01 and 1 mg/*l* depending on coal content and fly ash collection techniques.

The leachate quality of rainwater percolated through untreated FGD waste attains a nearly constant TDS content of 2000 mg/*l*, primarily sulfate salts, after passage of five pore volume displacements (PVD). Initial leachate content is as high as the soluble chemical content and is dependent upon the type of FGD system.

Chemical treatment has been found to have major benefits which effectively minimize (and possibly, in some cases, virtually eliminate) the release of leached sludge constituents to the subsoil through (a) the decreased permeability of the treated material, and (b) the amenability of the treated material to compaction and contouring during placement so that standing water does not occur on the disposal site. The prevention of standing water avoids having a hydraulic head on the site and, therefore, seepage through the pores does not occur as a result of hydraulic pressure. This is accomplished by managing the site so that a major portion of the rainfall on such a site runs off and is collected in a peripheral ditch which directs the water to a settling pond, from which decanted liquor is disposed of in an adjacent stream, if acceptable, or returned to the power plant water reuse system.

2.3 POTENTIAL ENVIRONMENTAL IMPACT

Because of high concentrations of salts and total dissolved solids, the presence of trace elements, and, in some cases, extreme values of pH and chemical oxygen demand (COD), untreated sludges (solids or liquids) are not suitable for direct disposal into water supplies. Also, because of the highly water retentive property of the material, it requires special handling, conditioning, or chemical treatment in its disposal to make the disposal site reclaimable. Regardless of the type of handling or treatment in disposal, consideration must be given to seepage to groundwater, runoff to streams, intrusion into irrigation systems, direct impact on vegetation, and impact on ocean life if disposed of at sea.

2.4 WASTE DISPOSAL

Various forms of disposal are being used and considered, and a selection depends on the environmental acceptability and processing cost in combination with the following factors, which are generally site specific: characteristics of the waste, climate, geology, topography, hydrology, and disposal site availability and proximity. Because of environmental concerns related to disposal of the FGD wastes, several alternatives are being studied, including variations within each alternative. The alternatives include: ponding on indigenous clay soil; ponding with a flexible liner of impervious soil; ponding with underdrainage; mine disposal; ocean disposal (possibly); and chemical treatment with landfilling. Ponding and landfill disposal are both current practices, but improvements in environmental protection and in costs associated with these methods are emerging through a combination of EPA and private-industry efforts. Mine disposal, particulary coal-mine disposal, of FGD wastes is being considered by private industry and, according to EPA studies to date, some forms of mine disposal appear quite promising. Ocean disposal is currently under study and, although a degree of uncertainty exists regarding its viability, several approaches appear promising. All disposal methods require monitoring, and land disposal sites require management throughout their active life, including special provisions such as covering the site with soil and the growth of vegetation to prevent either rewetting the material or runoff problems, as applicable.

2.5 UTILIZATION

Three major products which can be produced from flue gas scrubbing are gypsum from nonregenerable systems and sulfur and sulfuric acid from regenerable systems. Although the quality of the products produced may be equivalent to those obtained from current sources, the economics, however, are generally not favorable when compared with current sources of supply. Gypsum is not directly cost competitive; however, in consideration of sludge disposal credits for disposal under certain conditions, it can be shown to be a cost-effective commercial item. Sulfuric acid would have to compete in an industry that is currently capable of producing 30 percent over demand. However, there may be site-specific instances where the production of sulfur or sulfuric acid from regenerable scrubber systems may be economically feasible. Attempts are being made to develop other products from sulfur sludge, such as fertilizer and building materials.

2.6 ECONOMICS

Cost estimates have been made for disposal of sulfur sludges by various methods, as well as projected costs on a national basis to 1998 for the same methods considering current NSPS, and the two alternative revisions, i.e., 90 percent SO_2 removal and 0.5 lb $SO_2/10^6$ Btu. A summary of disposal costs, including conversion to gypsum and its disposal, is as follows:

DISPOSAL COSTS (mills/kWh)[a, b] (1977 DOLLARS)

Untreated Waste		Landfill-Chemical Treatment	Mine[c]	Ocean[d]	Gypsum[e]
Liner Added	Indigenous Clay				
1.02	0.70	1.33	0.37	2.38	1.39

[a] 500-MW plant, 3.5% sulfur coal, 90% SO_2 removal. Disposal site within 1 mile from plant except as noted.

[b] All disposal includes ash.

[c] Untreated waste, site located 4 miles from power plant.

[d] Treated sludge, on the continental shelf, 25 miles from the eastern seaboard.

[e] Cost of forced oxidation and disposal of gypsum including fly ash in an indigenous clay-lined pond.

An example is given below of the costs for disposal that would be incurred in 1998 if all new plants used nonregenerable scrubbing. Notes a through d above apply.

CUMULATIVE COSTS TO 1998 - BILLIONS (1977 DOLLARS)

Emission Standard	Liner Added	Indigenous Clay	Landfill-Chemical Treatment	Mine	Ocean
1.2 lb $SO_2/10^6$ Btu	1.41	0.95	1.89	0.58	2.84
90% SO_2 removal	1.54	1.04	2.07	0.64	3.12
0.5 lb $SO_2/10^6$ Btu	1.06	0.72	1.43	0.44	2.15

SECTION III

QUANTIFICATION OF SOLID WASTES

The solid wastes resulting from the scrubbing of flue gases from coal-fired steam generating utility boilers were quantified for 1000-, 500-, and 25-MW units in accordance with the study requirements (3), as shown in Table 6, for the following types of scrubbing processes: (a) nonregenerable: lime, limestone, and double alkali, and (b) regenerable: magnesium oxide and Wellman-Lord.

3.1 BASIS FOR THE STUDY

The quantities and types of wastes generated by various coal types and scrubbing processes were computed on the basis of the individual plant as well as national totals.

3.1.1 Plant Installation Basis

The annual quantities produced and the disposal site volume needed as a result of the following three emission limits were calculated, i.e., (1) current New Source Performance Standards (NSPS) requirements of 1.2 lb SO_2 emitted per million Btu heat input, (2) 90 percent SO_2 removal by scrubbing, regardless of sulfur content in the coal, and (3) a 0.5 lb SO_2 per million Btu. In addition to the effects of boiler size, the sulfur content of the coal was a major input parameter. Typical western coal (0.8 percent sulfur) and eastern (3.5 and 7.0 percent sulfur) were considered. Other coal characteristics are summarized in Table 7. In meeting a standard of 0.5 lb $SO_2/10^6$ Btu, coal washing that removed 40 percent of the sulfur in the coal was also included.

Five basic scrubbing processes, i.e., lime, limestone, double alkali, magnesium oxide, and Wellman-Lord, were modeled (see Figures 2 through 4). Calculations to determine waste quantities and volume for the various alternative plant sizes and FGD systems were performed. These were keyed to the model plants and standards defined in Table 6 and assigned case numbers (Table 8) for ease of identification. This resulted in a total of 67 cases. Additionally, about 24 other cases were computed to elucidate various aspects of the study, such as a comparison of high- and low-sulfur coals, the effect of various degrees of coal washing, and the SO_2 removal requirements to achieve emissions of 0.5 lb $SO_2/10^6$ Btu. These cases are identified in Table 8 by three-digit numbers; the first two digits denote the

TABLE 6. ALTERNATIVE CONTROL SYSTEMS FOR MODEL PLANTS [a, b]

Plant Sizes To Be Considered, MW	FGD Systems To Be Considered	Alternative Standards and Model Plant Systems
25; 500; 1000	5[c]	1. The existing NSPS of 1.2 lb $SO_2/10^6$ Btu heat input. a. 90-percent SO_2 removal on a plant burning a typical coal of 3.5 percent sulfur.
25; 500; 1000	Lime/limestone	b. A plant burning a typical 7-percent sulfur coal with 90-percent SO_2 removal by FGD.
25; 500	---	c. Low-sulfur coal without FGD for a typical eastern plant.
25; 500	---	d. Low-sulfur coal without FGD for a typical western plant.
500	Lime/limestone	e. 40-percent sulfur removal by coal washing of a 3.5-percent-sulfur coal followed by 65-percent SO_2 removal by FGD.
25; 500; 1000	5[c]	2. a. 90-percent SO_2 removal by FGD on a typical coal of 3.5 percent sulfur and a typical coal of 7 percent sulfur.
25; 500	Lime/limestone	b. 90-percent SO_2 removal by FGD on a plant burning a typical western coal of 0.8 percent sulfur (western plant).
25; 500	Lime-limestone	3. 0.5 lb SO_2 emissions/10^6 Btu heat input. a. 70- to 75-percent SO_2 removal by FGD on a 0.8-percent-sulfur western coal (western plant).
25; 500	Lime/limestone	b.1 40-percent sulfur removal by coal washing of a 3.5-percent-sulfur coal and 85-percent removal by FGD.
500	Lime/limestone	b.2 40-percent sulfur removal by coal washing of a 7-percent-sulfur coal and 95-percent removal by FGD.

[a] Reference 3.

[b] Per References 1 and 2.
- o Study encompasses 1978-1998 period.
- o More stringent standards to apply in 1980.
- o New plant installed capacity per Federal Power Commission projections.
- o For 1980 and thereafter, 45 percent of the coal burned nationally is western, low sulfur.

[c] The five systems to be considered are lime, limestone, magnesium oxide, double alkali, and Wellman-Lord.

TABLE 7. COAL CHARACTERISTICS USED IN STUDY

A. Typical Coals

Coal Type	Percent Sulfur	Heating Value, Btu/lb	Percent Ash
1. Typical eastern	3.5	12,000	14
2. High sulfur	7.0	12,000	14
3. Typical western low-sulfur			
a. High Btu	0.8	10,000	8
b. Low Btu	0.8	8,000	6
4. Eastern low-sulfur	0.8	13,500	6
5. Western coal meeting or bettering current NSPS.			
a. High Btu	0.6	10,000	8
b. Low Btu	0.4	8,000	6

B. Effect of Coal Washing

Coal Type	Sulfur Removed, Percent	Percent Sulfur		Heating Value, Btu/lb		Percent Ash	
		Unwashed	Washed	Unwashed	Washed	Unwashed	Washed
1. Typical eastern	40	3.5	2.1	12,000	13,200	14	9.2
2. High sulfur	40	7.0	4.2	12,000	13,200	14	4.0

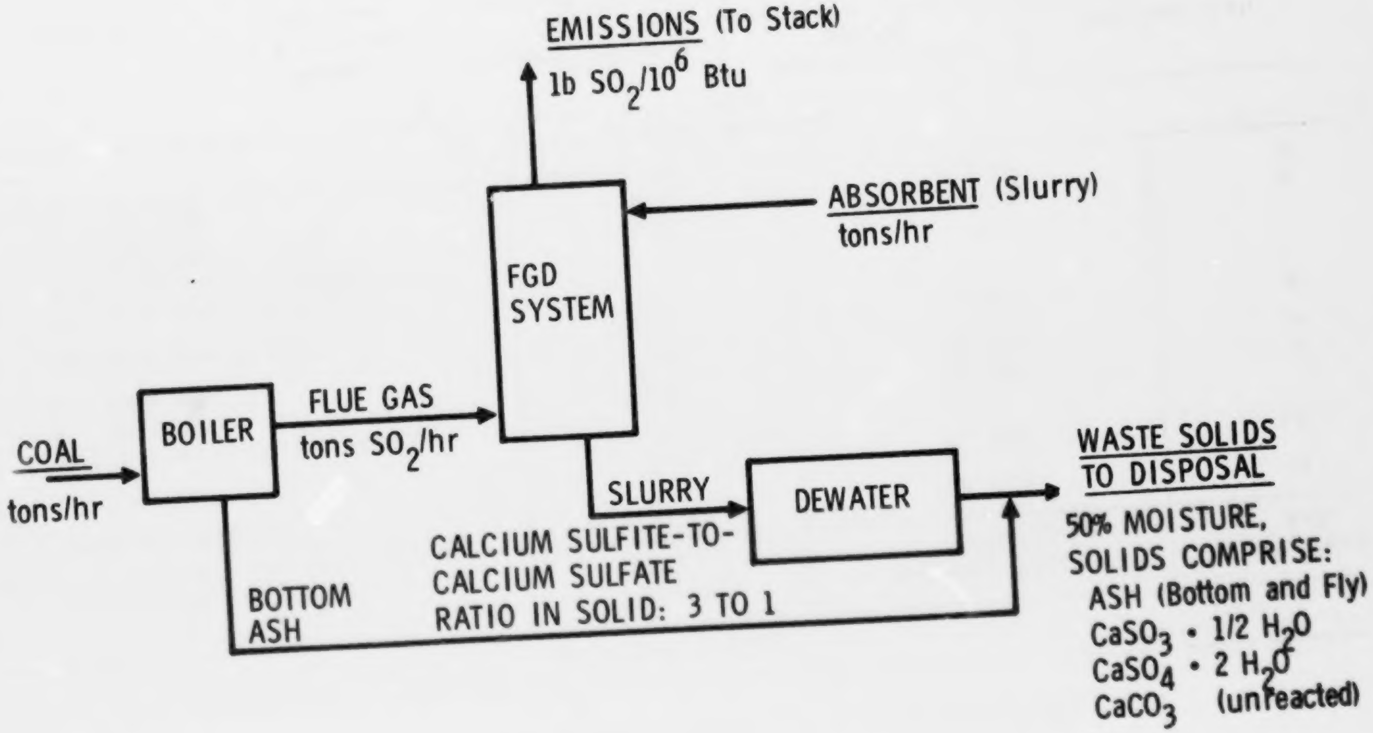

EMISSIONS (To Stack)
1b $SO_2/10^6$ Btu
ABSORBENT (Slurry)
tons/hr
FGD SYSTEM
COAL
tons/hr
BOILER
FLUE GAS
tons SO_2/hr
SLURRY
DEWATER
BOTTOM ASH
CALCIUM SULFITE-TO-CALCIUM SULFATE RATIO IN SOLID: 3 TO 1
WASTE SOLIDS TO DISPOSAL
50% MOISTURE,
SOLIDS COMPRISE:
ASH (Bottom and Fly)
$CaSO_3 \cdot 1/2\ H_2O$
$CaSO_4 \cdot 2\ H_2O$
$CaCO_3$ (unreacted)

Figure 2. Lime and limestone scrubbing: block diagram.

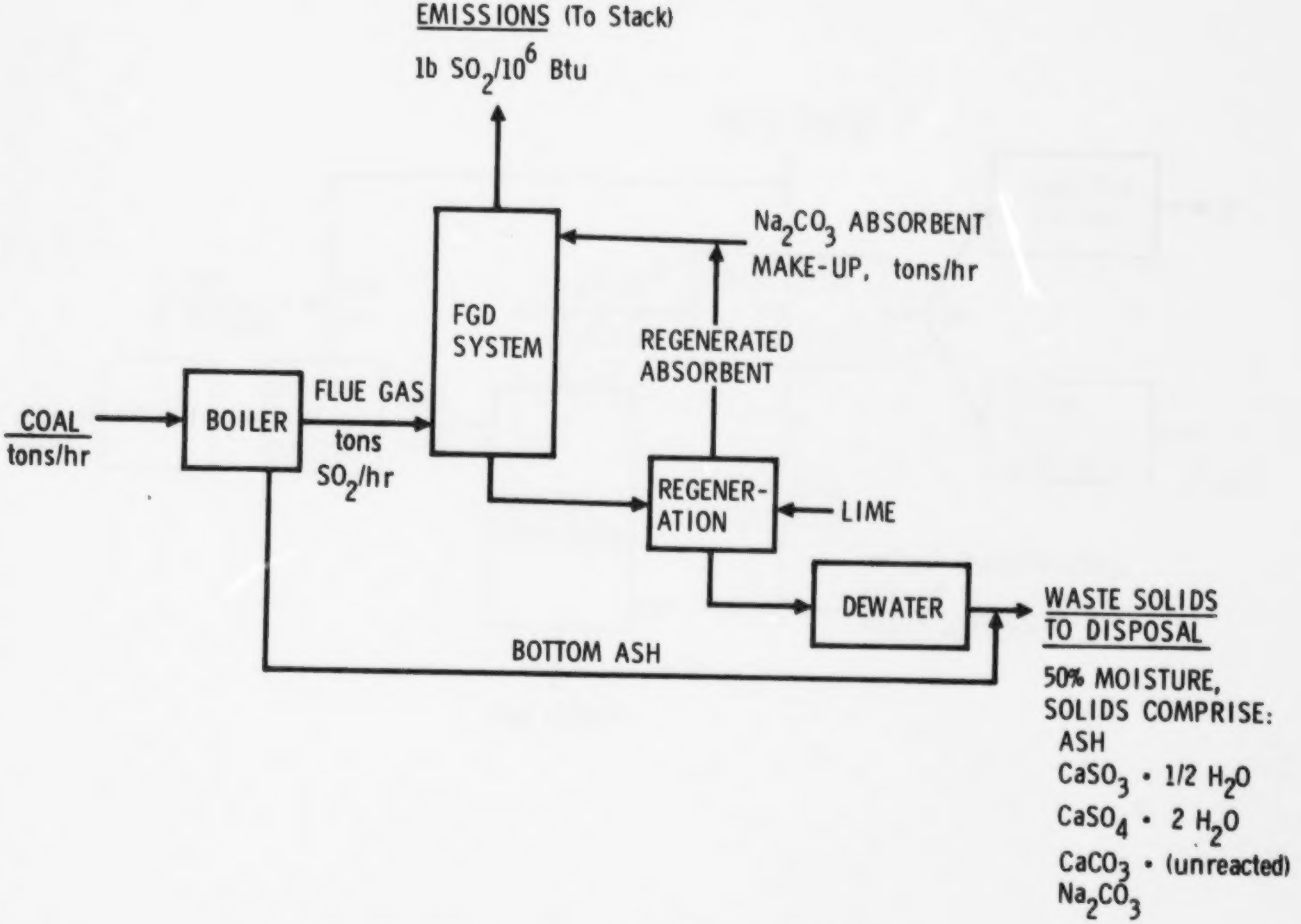

EMISSIONS (To Stack)
lb $SO_2/10^6$ Btu
COAL
tons/hr
BOILER
FLUE GAS
tons
SO_2/hr
FGD SYSTEM
Na_2CO_3 ABSORBENT
MAKE-UP, tons/hr
REGENERATED ABSORBENT
REGENER-ATION
LIME
DEWATER
BOTTOM ASH
WASTE SOLIDS TO DISPOSAL
50% MOISTURE,
SOLIDS COMPRISE:
ASH
$CaSO_3 \cdot 1/2\ H_2O$
$CaSO_4 \cdot 2\ H_2O$
$CaCO_3$ • (unreacted)
Na_2CO_3

Figure 3. Double-alkali scrubbing: block diagram.

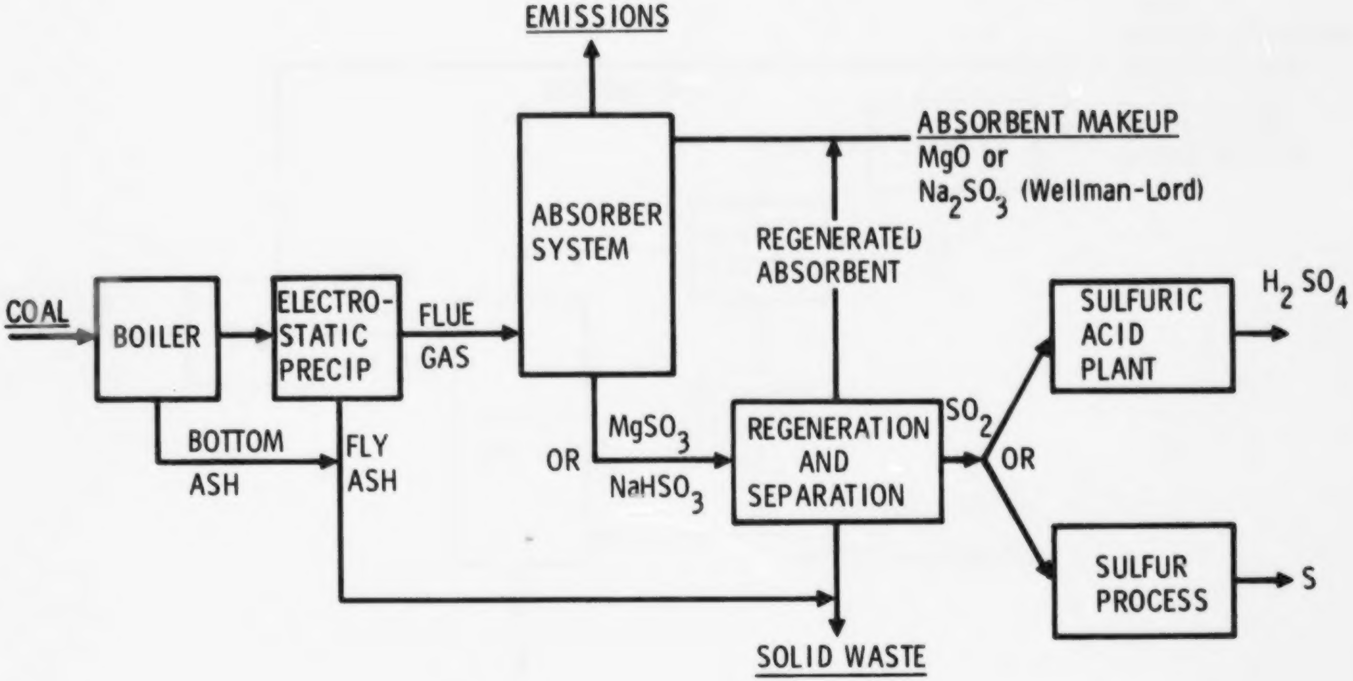

EMISSIONS
ABSORBENT MAKEUP
MgO or
Na_2SO_3 (Wellman-Lord)
ABSORBER SYSTEM
REGENERATED ABSORBENT
COAL
BOILER
ELECTRO-STATIC PRECIP
FLUE GAS
H_2SO_4
SULFURIC ACID PLANT
BOTTOM ASH
FLY ASH
OR
$MgSO_3$
$NaHSO_3$
REGENERATION AND SEPARATION
SO_2
OR
SULFUR PROCESS
S
SOLID WASTE

Figure 4. Magnesium oxide and Wellman-Lord processes: generalized block diagram.

TABLE 8. CROSS REFERENCE OF ALTERNATIVE STANDARDS AND MODEL PLANTS WITH STUDY CASE NUMBERS

Alternative Standards and Model Plant Systems	Plant Sizes, MW	FGD Systems	Case Numbers
1. Meets existing NSPS of 1.2 lb $SO_2/10^6$ Btu heat input			
a. 80% SO_2 removal, plant burning typical coal with 3.5% sulfur, 12,000 Btu/lb, 14% ash	1000 500 25	Lime Limestone Double alkali Magnesium oxide Wellman-Lord	1 - 3 4 - 6 7 - 9 10 - 12 13 - 15
b. 90% SO_2 removal, plant burning coal with 7% sulfur, 12,000 Btu/lb, 14% ash	1000 500 25	Lime Limestone	16 17 18 19 20 21
c. No FGD, low sulfur coal, typical eastern plant, 0.8% sulfur, 13,500 Btu/lb, 6% ash	500 25	None	22 23
d.1 No FGD, low-sulfur coal, typical western plant, 0.6% sulfur, 10,000 Btu/lb, 8% ash	500 25	None	24 25
d.2 No FGD, low-sulfur coal, typical western plant, 0.4% sulfur, 8000 Btu/lb, 6% ash	500 25	None	241 251
e. 40% sulfur removal by coal washing of a 3.5% sulfur coal, followed by a 65% SO_2 removal by FGD. Prewash coal: 12,000 Btu/lb, 14% ash	500	Lime Limestone	26 27

(continued)

TABLE 8. (Continued)

Alternative Standards and Model Plant Systems	Plant Sizes, MW	FGD Systems	Case Numbers
2. 90% SO_2 removal by FGD			
a. 1 Plant burning typical 3.5% sulfur coal, 12,000 Btu/lb, 14% ash	1000 500 25	Lime Limestone Double alkali Magnesium oxide Wellman-Lord	28 - 30 31 - 33 34 - 36 37 - 39 40 - 42
a. 2 Plant burning 7% sulfur coal, 12,000 Btu/lb, 14% ash	1000 500 25	Lime Limestone Double alkali Magnesium oxide Wellman-Lord	43 - 45 46 - 48 49 - 51 52 - 54 55 - 57
b. 1 Western plant burning typical 0.8% sulfur western coal, 10,000 Btu/lb, 8% ash	500 25	Lime Limestone	58 - 59 60 - 61
b. 2 Western plant burning typical 0.8% sulfur western coal, 8000 Btu/lb, 6% ash	500 25	Lime Limestone	581 - 591 601 - 611
3. Meets more stringent standard of 0.5 lb $SO_2/10^6$ Btu heat input			
a. 1 70% SO_2 removal on 0.8% sulfur coal, 10,000 Btu/lb, 8% ash	500 25	Lime Limestone	62 - 63 64 - 65

(continued)

TABLE 8. (Continued)

Alternative Standards and Model Plant Systems	Plant Sizes, MW	FGD Systems	Case Numbers
3. (continued)			
a.2 75% SO_2 removal on 0.8% sulfur coal, 8000 Btu/lb, 6% ash	500	Lime	621 - 631
	25	Limestone	641 - 651
b.1 40% sulfur removal by coal washing of a 3.5% sulfur coal, followed by a 85% SO_2 removal by FGD. Pre-wash coal: 12,000 Btu/lb, 14% ash	500	Lime	66 - 67
	25	Limestone	68 - 69
b.2 40% sulfur removal by coal washing of a 7% sulfur coal, followed by a 95% SO_2 removal by FGD. Pre-wash coal: 12,000 Btu/lb, 14% ash	500	Lime	70
		Limestone	71

study case that most closely applies; the third digit, starting with 1, is the sub-case number. The detailed results are tabulated in Appendix A. A general discussion is provided in Section 3.2, and the effects of the various parameters are discussed in Sections 3.3 through 3.6.

Additionally, calculations were made defining the SO_2 emissions, the amount of coal burned, the quantities of absorbent required, the quantities of SO_2 produced and scrubbed, and the composition of the wastes. For the regenerable processes, the quantities of sulfuric acid or elemental sulfur that could be produced were also computed. Tables 9 and 10 itemize the various input and output parameters and illustrate the listing and format of the computer output.

The effects of coal washing to remove inorganic sulfur prior to burning the coal were also assessed in a number of cases. A schematic of the process and the algorithms associated with the calculations are shown in Figure 5; the results are discussed in Section 3.7.

Input quantities relating to plant operation, coal consumption, and scrubber absorbent utilization are summarized in Tables 11 and 12.

3.1.2 Nationwide Basis

The waste quantities generated as a result of the nonregenerable and regenerable processes were computed for the time span of 1978 through 1998. The total annual installation of new and modified coal-fired sources (2) are shown in Figure 6. The reference conditions for use in the national waste projections were a 3.5-percent-sulfur coal for eastern use and 0.8-percent sulfur in the west, and considering that the annual generating capacity (and quantities of waste produced) was from 500-MW plants. As will be shown later (Section 3.4), this base-case installation of 500 MW is not only the approximate average size being built but also the installation that produces waste quantities within 5 percent of the anticipated extremes. The 3.5-percent and 0.8-percent sulfur was defined (1) as being typical levels in nationwide (eastern and western) use. The estimated fraction of plants on a nationwide basis using western coal in 1980 is 45 percent (4). This was based on the referenced projection that 45 percent of the coal burned at that time would be low sulfur from western sources. However, application of more stringent standards would possibly affect the percent of western coal used. Since predictions of the impacts were not available, the effects resulting from the use of discrete fractions of eastern coal were computed and are presented in Appendix B for 25, 40, 55 (base case, 45 percent western), 70, and 85 percent of the coal burned nationally from eastern sources.

The total dry waste tonnage produced in the years 1985 and 1998 for the three emission alternatives for a 500-MW plant are shown in Figure 7. The data include only the waste produced by nonregenerable scrubber systems at the generating plant, and therefore the 0.5-lb $SO_2/10^6$ Btu case does not include the coal wash tailings left at the mine site.

TABLE 9. FORMAT FOR LIME AND LIMESTONE AND DOUBLE-ALKALI SCRUBBERS

```
 INPUT:
 CASE  #- PROCESS TITLES AND OPTIONS
 % SULFUR  FUEL,BTU   FUEL %   CAPACITY   FUEL BTU ABSORBENT % SO2 REM  % MOIST
  IN FUEL   PER LB     ASH        MW      PER KWH  UTILIZ, %  BY SCRUB.  IN WST

SULFITE-   DENSITY,  SODA ASH   PLANT    % SULFUR   DENSITY   % MOIST   FUEL
TO SULFATE WET WASTE MAKE UP  OPERATING  REMOVED  OF TAILING    IN      WASH
 RATIO     LB/FT3       %       HOURS    IN WASH    LB/FT3    TAILING   FACTOR


 OUTPUT:
  FUEL       TOTAL      SO2       SO2     ABSORBENT   SO2        SO2       SO2
 BURNED,     SULFUR    FORMED    REMOVED     USED   EMISSIONS EMISSIONS LB/M BTU
   T/H        T/H       T/H       T/H        T/H      T/H       LB/H

   ASH       PRECIP
  FORMED     CaCO3     CaSO3      CaSO4      % ASH     % CaCO3   % CaSO3   % CaSO4
   T/H        T/H       T/H        T/H     DRY WASTE DRY WASTE DRY WASTE DRY WAST

  TOTAL      TOTAL     TOTAL      TOTAL    TOTAL WET  TOTAL WET  TOTAL
 DRY WASTE WET WASTE DRY WASTE WET WASTE   VOL,FT3/   VOL,ACRE   BTU/HR
   T/H        T/H       T/Y        T/Y       YEAR     FEET/YEAR

* TAILING    TAILING   TAILING   TAILING    TAILING   TAILING   % ASH IN  AMT OF
  DRY,T/H    WET,T/H   DRY,T/Y   WET,T/Y    VOL,FT3/  VOL,ACRE   WASHED    FUEL
                                              YEAR    FEET/YEAR   FUEL

* SODA ASH % SODA ASH
   T/H      IN WASTE

 * These lines printed only if the options are invoked.

 T/H = TONS PER HOUR (SHORT TONS)
 T/Y = TONS PER YEAR (SHORT TONS)
 LB/H= POUNDS PER HOUR
 SODA ASH FROM DOUBLE ALKALI OPTION

 TAILINGS: FROM COAL WASHING OPTION
```

TABLE 10. FORMAT FOR MAGNESIUM OXIDE AND WELLMAN-LORD PROCESSES

```
INPUT:

CASE  #- PROCESS TITLES AND OPTIONS
% SULFUR  FUEL,BTU   FUEL %   CAPACITY   FUEL BTU    N/A    % SO2 REM   % MOIST
 IN FUEL   PER LB     ASH        MW      PER KWH            BY SCRUB.    IN WST

 REGEN    SOLID WST  ABSORB     PLANT     H2SO4    SULFUR,%
 EFF,%    DENSITY,   MAKEUP   OPERATION   % CONV.    CONV.
           LB/FT3    PERCENT     H/Y

*% SULFUR DENSITY    PERCENT    FUEL
 REMOVED  OF TAILING MOIST IN   WASH
 IN WASH  LB/FT3     TAILING   FACTOR


OUTPUT:
 FUEL      TOTAL      SO2       SO2      SO2       SO2       TOTAL    SO2
BURNED,   SULFUR     FORMED   REMOVED  EMISSIONS EMISSIONS   BTU/HR  LB/M BTU
  T/H       T/H        T/H       T/H      T/H       LB/H

DRY WASTE WET WASTE  DRY ASH  PROCESS    REGEN     % ASH,  % PROCESS   % REGEN
   T/H       T/H       T/H SOLID DRY  SOLID DRY   DRY    SOLID,DRY   SOLID DRY
                             WASTE,T/H  WASTE,T/H   WASTE   WASTE      WASTE

  TOTAL     TOTAL    TOTAL    TOTAL WET   TOTAL    TOTAL     TOTAL      TOTAL
DRY WASTE WET WASTE  WET VOL  VOL, ACRE   H2SO4    H2SO4     SULFUR,   SULFUR,
   T/Y       T/Y     FT3/Y    FEET/YEAR    T/H      T/Y       T/H        T/Y

* TAILING  TAILING   TAILING   TAILING   TAILING   TAILING   % ASH IN   AMT OF
  DRY,T/H  WET,T/H   DRY,T/Y   WET,T/Y   VOL,FT3/  VOL,ACRE   WASHED     FUEL
                                           YEAR    FEET/YEAR   FUEL
```

* These lines printed only if the fuel wash option is invoked.

T/H = TONS PER HOUR (SHORT TONS)

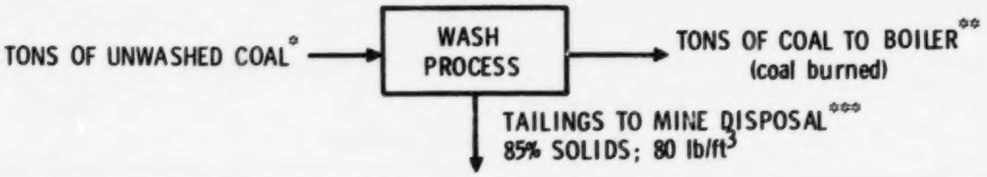
T/Y = TONS PER YEAR (SHORT TONS)

LB/H= POUNDS PER HOUR

TAILINGS: FROM COAL WASHING OPTION

PROCESS SOLID = ABSORBENT IN THE WASTE(DRY)

$$* \text{ TONS OF UNWASHED COAL} = \text{TONS OF COAL BURNED} \times \left[1 + \left(\frac{\text{\% S REMOVED IN WASH}}{100} \times \frac{\text{\% S IN UNWASHED COAL}}{100} \times \frac{\text{MOL WT}_{\text{Fe S}_2}}{2 \text{ MOL WT}_S} \times 2.0\right)\right]$$



$$*** \text{ TONS OF DRY TAILINGS} = \left(\frac{\text{\% S REMOVED IN WASH}}{100} \times \frac{\text{\% S IN UNWASHED COAL}}{100} \times \frac{\text{MOL WT FeS}_2}{2 \text{ MOL WT}_S} \times 2.0\right) \times (\text{TONS OF COAL WASHED})$$

$$** \text{ TONS COAL BURNED PER HOUR} = (\text{PLANT CAPACITY})_{\text{KW}} \times \frac{\text{Btu}}{\text{kWh}} \times 1 \text{ hr} \times \left(\frac{1}{\text{HV}_{\text{Btu/lb}}}\right) \times \frac{1 \text{ ton}}{2000 \text{ lb}}$$

$$** \text{ \% S IN BURNED COAL} = \text{\% S IN UNWASHED COAL} \times \left(1 - \frac{\text{\% WASH}}{100}\right)$$

$$** \text{ \% ASH IN BURNED COAL} = \left(\frac{\left(\frac{\text{\% ASH}}{100} \times \text{WT UNWASHED COAL}\right) - \text{WT DRY TAILINGS}}{\text{WEIGHT BURNED COAL}}\right) \times 100$$

$$** \text{ HEAT VALUE OF BURNED COAL} = (\text{HV}) \text{ UNWASHED} + \left[0.10(\text{HV}) \text{ UNWASHED} \times \frac{\text{\% S WASH}}{40}\right]$$

NOTE: ALL QUANTITIES CALCULATED ON BASIS OF TONS (SHORT) PER HOUR
MOL WT = MOLECULAR WEIGHT OF FeS_2 AND SULFUR; 120 AND 32, RESPECTIVELY

Figure 5. Generalized diagram and algorithms for coal washing process.

TABLE 11. BASIC STEAM GENERATING PLANT CHARACTERISTICS USED IN STUDY

1. Energy Conversion Factors		
a.	1000 MW	8,700 Btu/kWh
b.	500	9,000
c.	25	10,080
2. Average Power Plant Operating Load Factor		
a.	50 percent	
b.	30-year operating lifetime	

TABLE 12. BASIC SCRUBBER AND FGD PROCESS CHARACTERISTICS USED IN STUDY

1. Absorbent Utilization	
a. Non-Regenerable	
(1) Lime	90%
(2) Limestone	80%
(3) Lime in double-alkali process	95%, with 3% Na_2CO_3 make-up[a]
b. Regenerable	
(1) Magnesium oxide[b]	
(a) 3% absorbent make-up (MgO)	
(b) 95% separation efficiency	
(2) Wellman-Lord[b]	
(a) 3% absorbent make-up (Na_2SO_3)	
(b) 95% separation efficiency	

---

[a] Percent (molar basis) of the absorbent lost in the regeneration process. Percentage based on the fraction of the amount of absorbent required to scrub the SO_2.

[b] Percent (molar basis) of the absorbent lost in the absorption, regeneration, and separation processes, including: 3% (absorbent equivalent) lost in the absorption-regeneration process due to its inefficiency and an additional 5% (absorbent equivalent) lost in the separation process due to its inefficiency (see Figure 3 for a schematic of the magnesium oxide and Wellman-Lord processes).

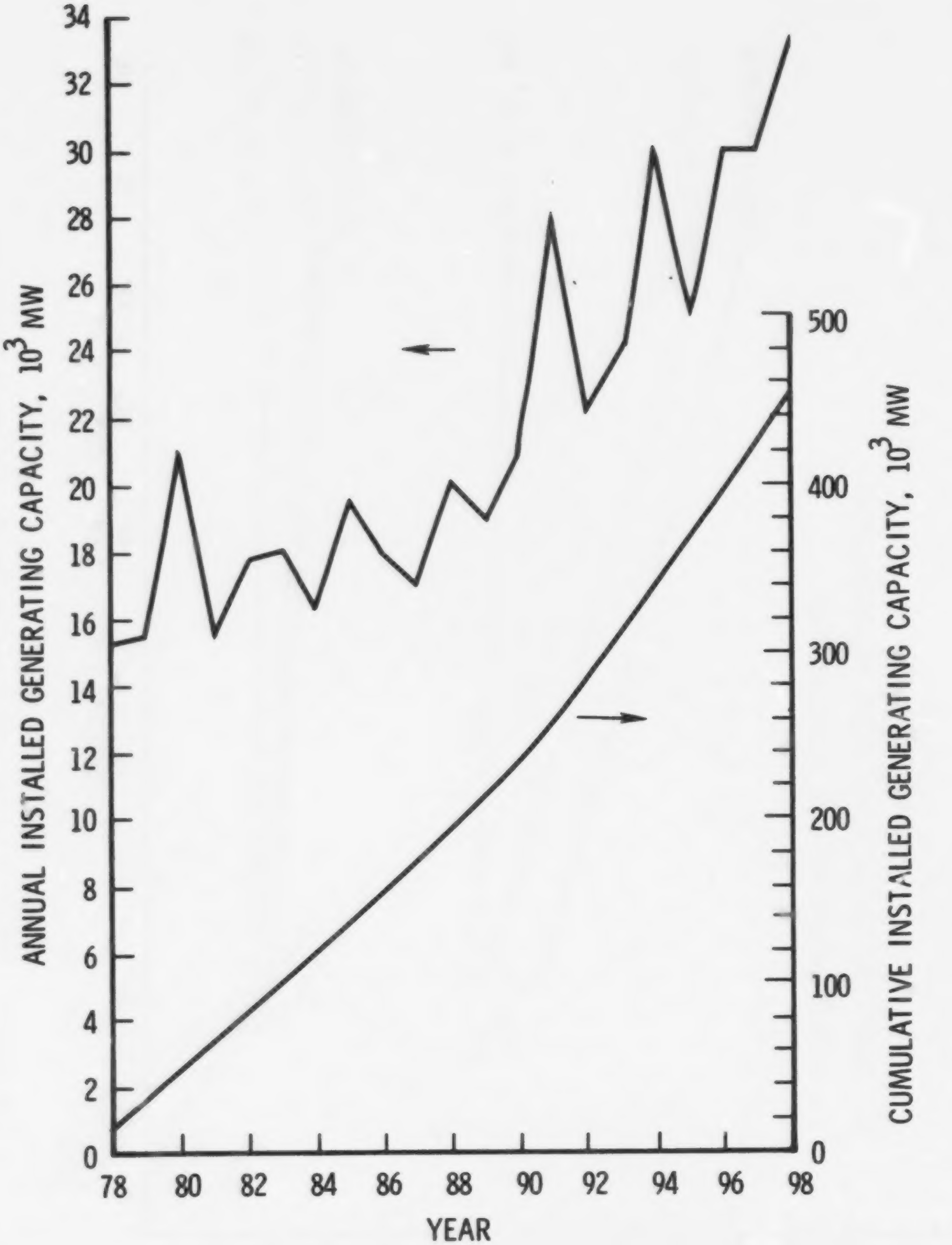


Figure 6. Annual and cumulative installed coal-burning plant capacity.

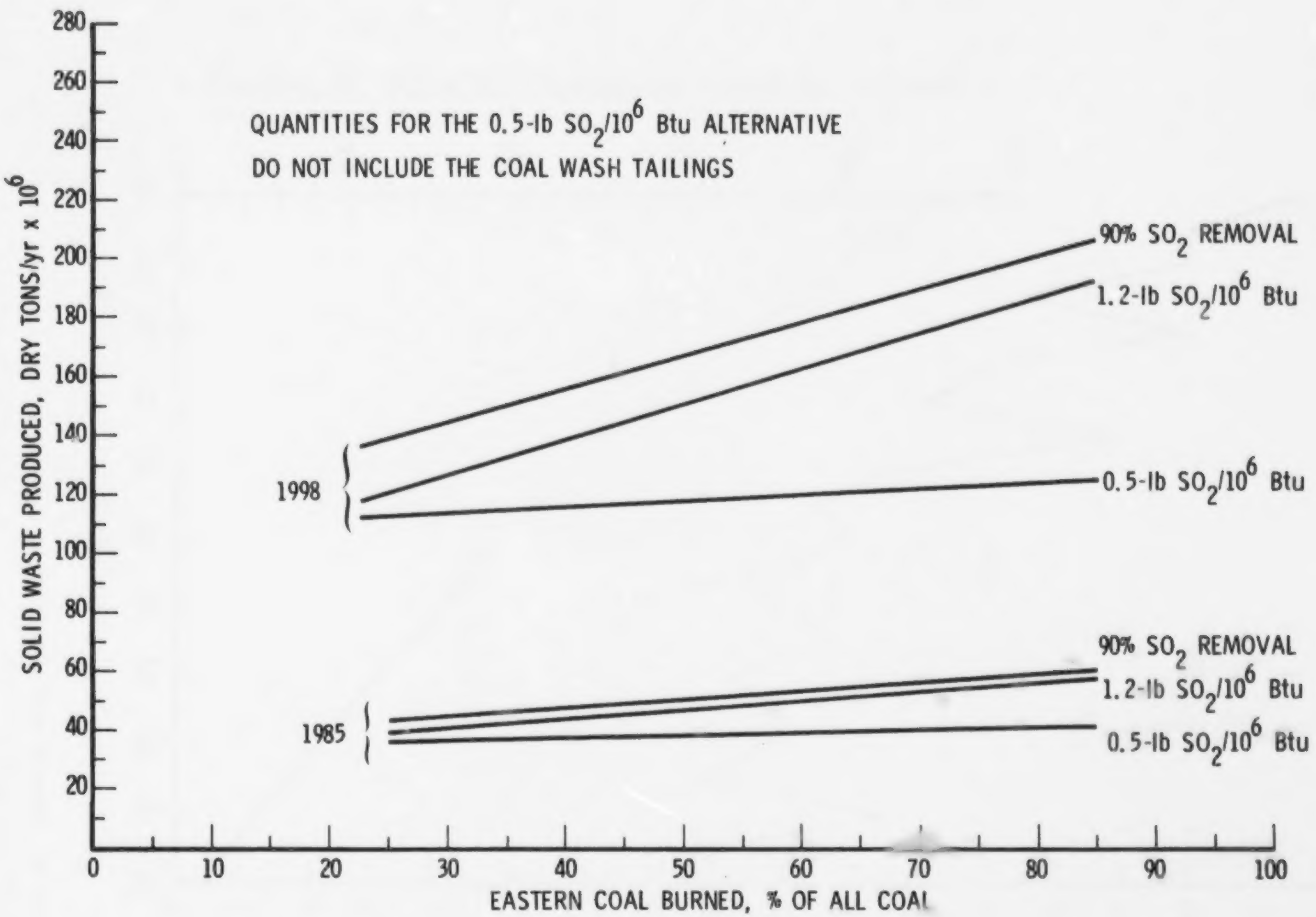


Figure 7. Effect of eastern coal use on nationwide waste quantities

The annual eastern and western waste production and land to be consumed by disposal were determined and then summed for the entire nation (Sections 3.8.1 and 3.8.2). Since the anticipated life of each plant is 30 years, the amount of land that must be allocated on a yearly basis and during the plants' lifetimes should be considered. Figure 8 depicts the flow diagram of the computation process used in the nationwide study.

The results are presented on the basis of the current federal NSPS standards being applicable through 1979. Thereafter, for 1980 through 1998, two more-stringent standards are considered alternatively; i.e., 90 percent SO_2 removal, and 0.5 lb $SO_2/10^6$ Btu.

To place these results in perspective, the effect of retaining the current standards in terms of waste generated and land-use requirements are also shown.

3.2 IMPLICATIONS OF CURRENT AND STRICTER NSPS EMISSIONS REGULATIONS ON SO_2 REMOVAL

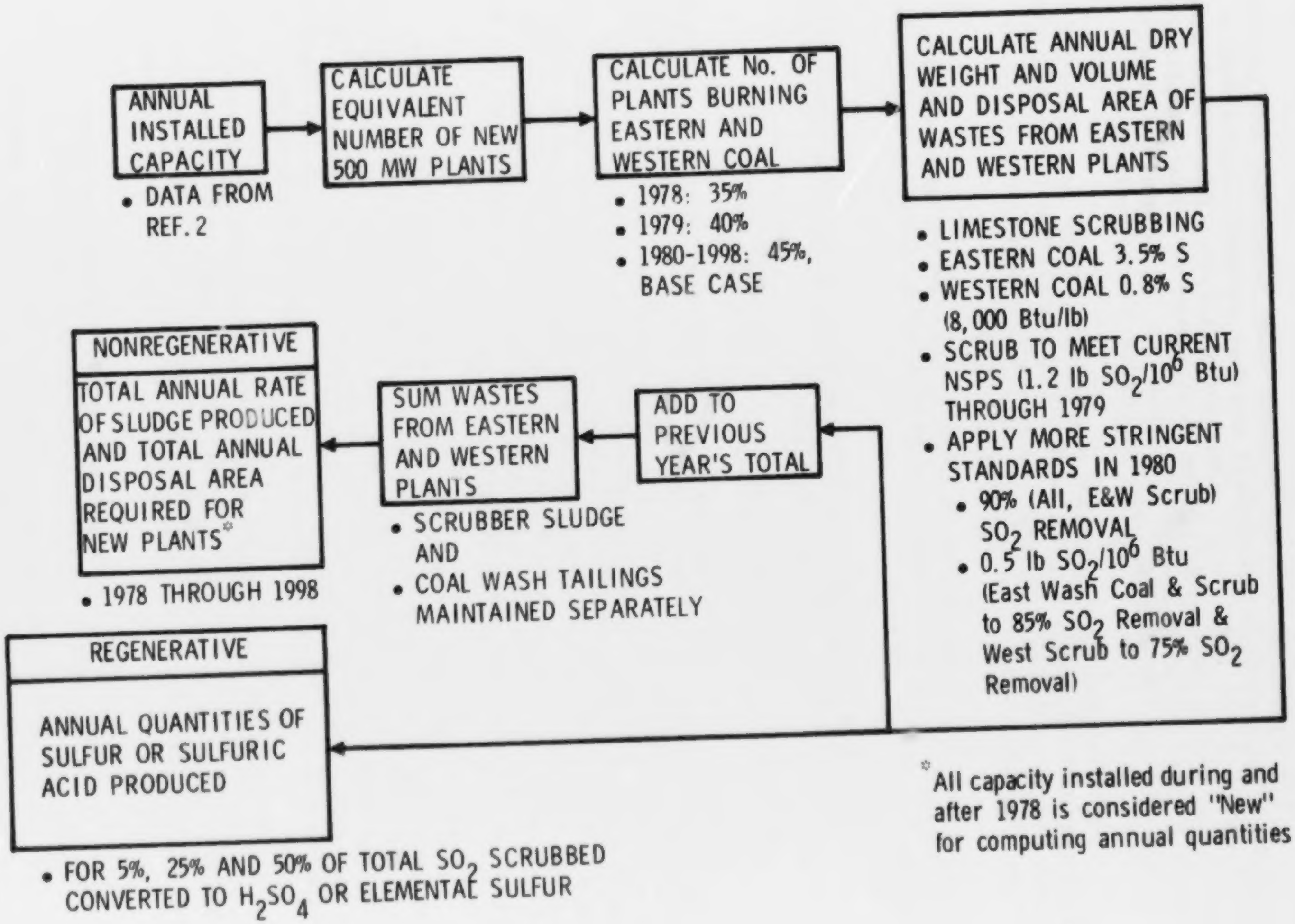
3.2.1 Current Federal Standards: 1.2 lb $SO_2/10^6$ Btu

Current federal standards limit SO_2 emissions to 1.2 lb $SO_2/10^6$ Btu. To achieve these conditions with typical 3.5-percent-sulfur eastern coal, 80-percent SO_2 removal by scrubbing is required (Table 13, Part A). If the coal is washed to remove 40 percent of the sulfur, only 65-percent SO_2 removal is needed and the scrubber sludge quantities (disposal at the power plant site) are reduced by 48 percent while producing tailings at the wash site (mine) amounting to 21 percent of the waste produced in the unwashed, 80-percent-removal case. The limitations of the coal washing process and the wastes produced are discussed further in Section 3.7.

With 7-percent-sulfur coal, 90-percent removal is required. With western coal (10,000 Btu/lb) a maximum sulfur content of 0.6 percent can be burned without scrubbing. With low Btu, low-sulfur coal (8,000 Btu/lb), a 0.4-percent sulfur content will result in emissions of 1.0 lb $SO_2/10^6$ Btu. Eastern low-sulfur coal, because of its higher heat content (13,500 Btu/lb), can contain up to 0.8 lb $SO_2/10^6$ Btu and still meet current standards.

A nomograph that may be used to determine the effect on emissions by various levels of scrubbing for a range of coals is provided in Figure 9. The only basic assumption made in its construction is that all the sulfur in the coal is oxidized to SO_2 and exits in the flue gas. As an example:

1. Connect the heating value and sulfur percent value to determine the unscrubbed emissions (line ①).
2. To determine the emissions after scrubbing, connect the unscrubbed emissions determined from step 1 and the percent SO_2 removed by scrubbing (line ②).


ANNUAL INSTALLED CAPACITY
• DATA FROM REF. 2
CALCULATE EQUIVALENT NUMBER OF NEW 500 MW PLANTS
CALCULATE No. OF PLANTS BURNING EASTERN AND WESTERN COAL
• 1978: 35%
• 1979: 40%
• 1980-1998: 45%, BASE CASE
CALCULATE ANNUAL DRY WEIGHT AND VOLUME AND DISPOSAL AREA OF WASTES FROM EASTERN AND WESTERN PLANTS
• LIMESTONE SCRUBBING
• EASTERN COAL 3.5% S
• WESTERN COAL 0.8% S (8,000 Btu/lb)
• SCRUB TO MEET CURRENT NSPS (1.2 lb SO2/10^6 Btu) THROUGH 1979
• APPLY MORE STRINGENT STANDARDS IN 1980
• 90% (All, E&W Scrub) SO2 REMOVAL
• 0.5 lb SO2/10^6 Btu (East Wash Coal & Scrub to 85% SO2 Removal & West Scrub to 75% SO2 Removal)
ADD TO PREVIOUS YEAR'S TOTAL
SUM WASTES FROM EASTERN AND WESTERN PLANTS
• SCRUBBER SLUDGE AND
• COAL WASH TAILINGS MAINTAINED SEPARATELY
NONREGENERATIVE
TOTAL ANNUAL RATE OF SLUDGE PRODUCED AND TOTAL ANNUAL DISPOSAL AREA REQUIRED FOR NEW PLANTS*
• 1978 THROUGH 1998
REGENERATIVE
ANNUAL QUANTITIES OF SULFUR OR SULFURIC ACID PRODUCED
• FOR 5%, 25% AND 50% OF TOTAL SO2 SCRUBBED CONVERTED TO H2SO4 OR ELEMENTAL SULFUR

*All capacity installed during and after 1978 is considered "New" for computing annual quantities

Figure 8. Flow diagram describing computation of annual nationwide SO_2 scrubber by-products

TABLE 13. CONDITIONS TO MEET VARIOUS PERFORMANCE STANDARDS

A. Conditions Required to Meet 1.2 lb $SO_2/10^6$ Btu (Max)

Coal			Study Case Numbers	Percent Removal SO_2 Required	Remarks
% S	Btu/lb	% Ash			
3.5	12,000	14	1-15	80	40% sulfur removal by coal washing, 1.11 lb $SO_2/10^6$ Btu
3.5	12,000	14	26-27	60	
7.0	12,000	14	16-21	90	High-Btu western coal[a]
0.6[a]	10,000	8	24-25	None	
0.4	8,000	6	241 and 251	None	Low-Btu western coal, 1.0 lb $SO_2/10^6$ Btu
0.8	13,500	6	22-23	None	Low-sulfur eastern coal

B. Emissions Resulting from 90% SO_2 Removal

Coal			Study Case Numbers	Emissions lb $SO_2/10^6$ Btu
% S	Btu/lb	% Ash		
3.5	12,000	14	28-42	0.6
7.0	12,000	14	43-57	1.2
0.8	10,000	8	58-61	0.16
0.8	8,000	6	581-611	0.2

C. Conditions Required to Meet 0.5 lb $SO_2/10^6$ Btu (max)

Coal			Study Case Numbers	% S Removed by Coal Wash	% S Removed by Scrubbing
% S	Btu/lb	% Ash			
3.5	12,000	14	66-69	40	85
3.5	12,000	14	661	None	91.5
7.0	12,000	14	70-71	40	95 (0.32 lb $SO_2/10^6$ Btu)
7.0	12,000	14	701 and 711	40	92.5
7.0	12,000	14	702	None	96
0.8	10,000	8	62-65	None	70
0.8	8,000	6	621-651	None	75

[a] Maximum percentage of sulfur to meet NSPS is 0.6.

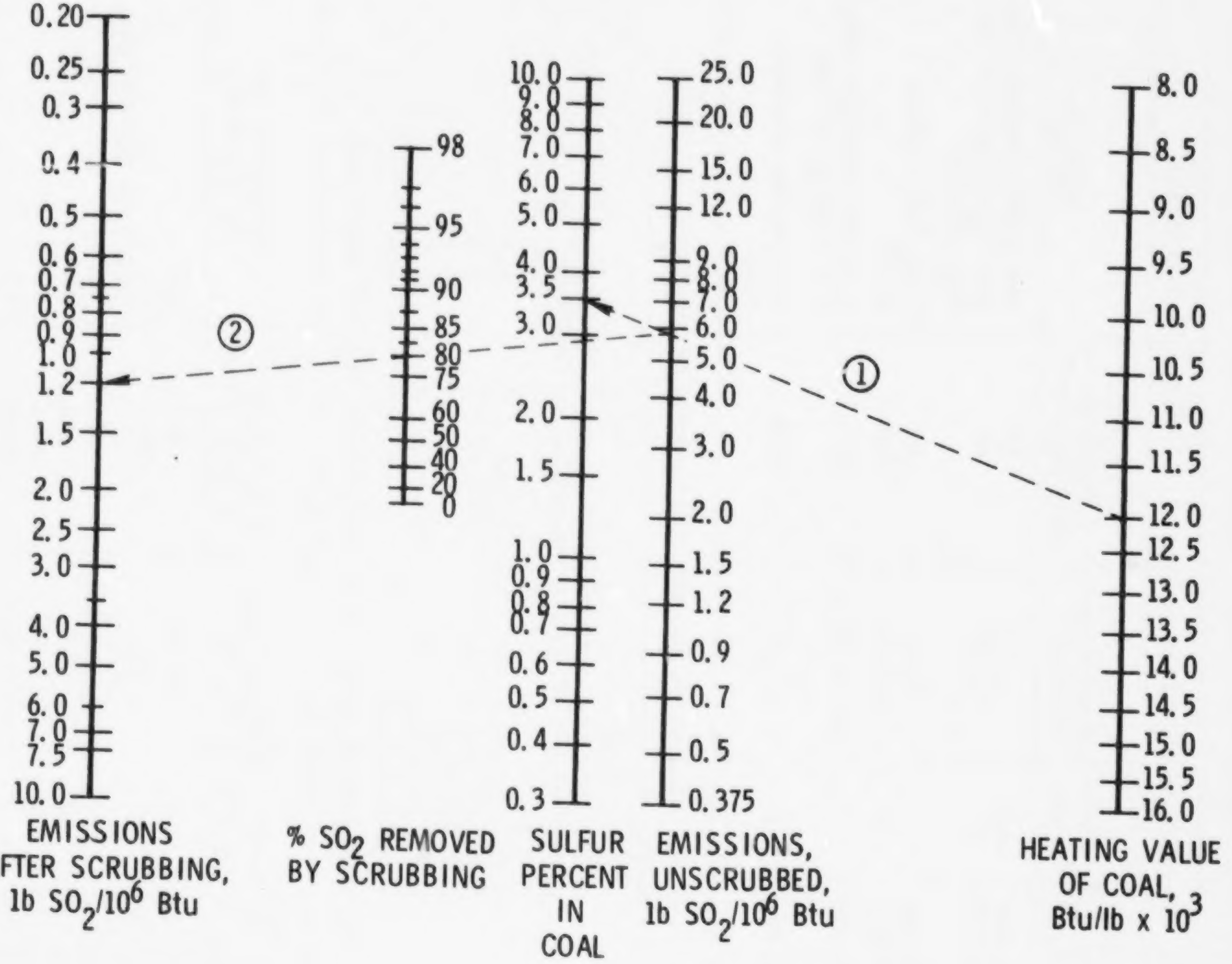


Figure 9. Nomograph: Relationship between coal properties and SO_2 emissions, with and without SO_2 scrubbing.

3.2.2 Ninety-Percent SO_2 Removal

If 90-percent SO_2 removal by scrubbing is considered, the resultant emissions for eastern 3.5- and 7.0-percent sulfur coal are 0.6 and 1.2 lb $SO_2/10^6$ Btu (Table 13, Part B). It is apparent that, for 90-percent scrubbing, a linear relationship exists between emissions and the sulfur content, providing that the Btu content of the coal remains constant (Figure 10).

For the range of western coals studied, 90-percent SO_2 scrubbing results in emissions of 0.16 to 0.20 lb $SO_2/10^6$ Btu.

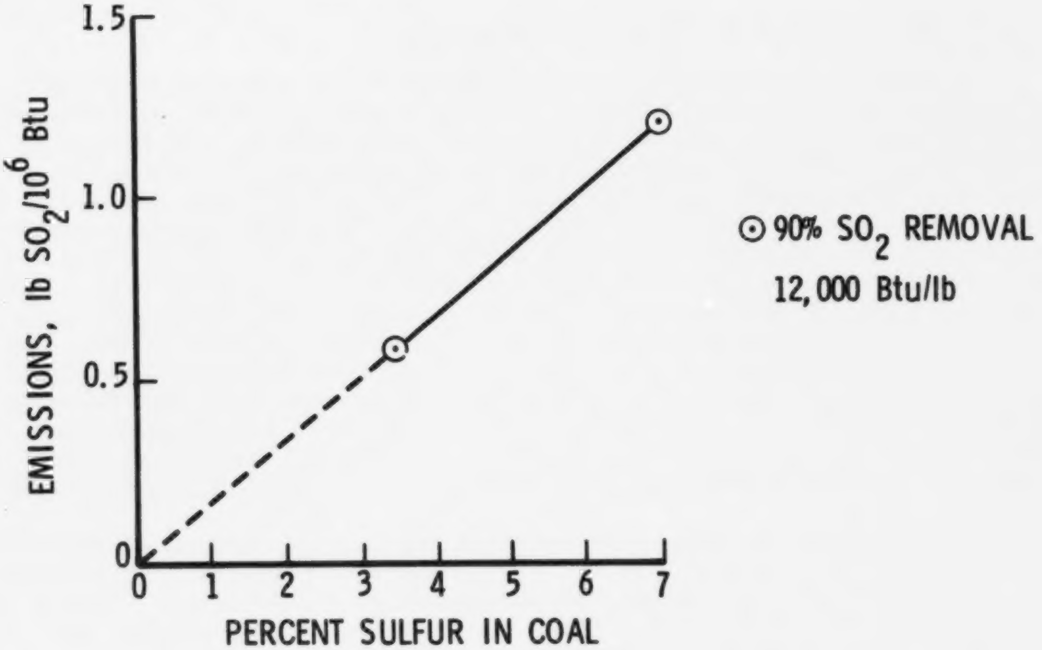


Figure 10. Effect of sulfur content on emissions for 90-percent SO_2 removal (heat content of coal = 12,000 Btu/lb)

3.2.3 More-Stringent Emissions Standard: 0.5 lb $SO_2/10^6$ Btu

The more-stringent requirement of 0.5 lb $SO_2/10^6$ Btu can be met with 3.5-percent-sulfur coal if it is scrubbed to remove 91.5 percent SO_2 (case number 661), or if the coal is washed and the resultant flue gas scrubbed to 85 percent (cases 66-69). See also Table 13, Part C.

With 7.0-percent-sulfur coal, 96-percent SO_2 removal is required without coal washing (case 702), or 92.5-percent SO_2 removal with 40-percent sulfur removal by coal washing (cases 701 and 711).

For western coal (0.8-percent SO_2) 70-percent scrubbing is needed for high (10,000 Btu/lb) coal and 75-percent scrubbing for the low, (8,000 Btu/lb) coal.

3.3 IMPLICATIONS OF NSPS REGULATIONS ON QUANTITIES OF WASTE PRODUCED

3.3.1 Nonregenerable Scrubbing Processes

The annual quantities of dry waste produced and total disposal areas resulting from the consideration of various federal standards are summarized in Table 14 for a typical 3.5-percent-sulfur eastern coal burned in a 500-MW plant and using a limestone scrubbing process. Tightening the standard from the current 1.2 lb $SO_2/10^6$ Btu to 90-percent SO_2 removal increases the wastes produced and disposal area required by approximately 6 percent from 233,000 tons/year (dry basis) and 302 acres (30-ft waste depth), respectively. A 0.5 lb $SO_2/10^6$ requirement necessitates a 91.5 percent SO_2 removal and results in a 7-percent increase in waste quantity and disposal area over the values needed to meet the current federal NSPS. The relative quantities produced by other processes; i.e., nonregenerable (lime and double alkali) and regenerable processes (magnesium oxide and Wellman-Lord) are comparable and are discussed in Section 3.5. Actual quantities for all the study cases are listed in Appendix A. The effects of power plant size and coal composition are discussed in Section 3.4 and 3.6, respectively.

A potential technique for reducing the amount of waste at the power plant to about 55 percent of that produced by meeting a standard by scrubbing only is to wash the coal and remove 40 percent of the sulfur before burning (cases 27 and 5, and 68 and 661). These cases produce wash tailings that total about 16 percent of the scrubber waste (without washing) and require considerably less equivalent disposal area. The weight, and moisture content, of the tailings is less than that of the scrubber sludge that would have been produced if the sulfur had not been washed, but had been burned in the coal and scrubbed. It appears that coal washing may be an attractive method to significantly reduce the amount of waste produced at the power plant and to reduce the

TABLE 14. WASTE[a] QUANTITIES AND DISPOSAL AREA FOR A 500-MW PLANT WITH LIMESTONE SCRUBBING

Coal			Emissions lb $SO_2/10^6$ Btu	% SO_2 Removed By Scrubbing	% S Removed in Coal by Washing	Scrubber Dry Waste Produced, Tons x 10^5/yr	Disposal Area Required[b], Acres	Case No.
% S	Btu/lb	% Ash						
3.5	12,000	14	1.2	80	None	2.334	302	5
3.5	12,000	14	1.2	60	40	1.215[c]	158[c]	27
3.5	12,000	14	0.6	90	None	2.482	322	32
3.5	12,000	14	0.5	91.5	None	2.504	324	661
3.5	12,000	14	0.5	85	40	1.377[c]	178[c]	68

[a] Includes ash

[b] For 30-yr plant life, 50% average load factor, disposal waste depth = 30 ft.

[c] 0.409×10^5 typical coal wash tailings (dry basis), 34 acres not included. These are assumed to be disposed of at the mine.

overall land requirement needed for the disposal of scrubber wastes. A more detailed discussion of the effects of coal washing on different coals is provided in Section 3.7.

3.3.2 Regenerable Processes

The wastes produced from the regenerable processes are primarily ash and sulfates purged from the processes; estimated as approximately 3 percent. The waste quantities produced and the areas required for disposal are listed in Table 15. The amounts of sulfuric acid or elemental sulfur potentially capable of being produced are also shown.

For a 500-MW plant approximately 120,000 tons per year (dry basis) of waste are produced, requiring slightly greater than 150 acres for disposal over a 30-year plant lifetime. Although the increase in wastes produced is barely perceptible when scrubbing going from an 80-percent SO_2 removal to a 90-percent removal, the amounts of sulfuric acid or sulfur are directly proportional to the scrubber removal efficiency. The wastes are primarily ash and affected only slightly by scrubber efficiency; to the extent of the slightly higher quantities of absorbent make-up.

3.4 EFFECT OF PLANT SIZE ON QUANTITIES OF WASTE PRODUCED

The wastes generated by power plants of different sizes are not directly proportioned to size (Figure 11). This is the result of higher operating efficiencies achieved by the larger plants. Therefore, a single 1000-MW plant produces wastes totalling approximately 96.5 percent of two 500-MW plants, and two 250-MW units produce about 1.8 percent more waste than one 500-MW unit. Therefore, in the range of most utility steam generating plants; i.e., 200 to 1000 MW, the amount of waste generated and disposal area required is within +2 to -4 percent of that produced by equivalent numbers of 500-MW units. This observation is important in the nationwide assessment of total quantities of waste produced because it substantiates the assumption that all the installed generating capacity can be characterized by an equivalent 500-MW plant and the study does not require a plant-by-plant summation.

3.5 EFFECTS OF THE SCRUBBING PROCESS ON QUANTITIES OF WASTE PRODUCED

The basic types of wet scrubbing processes examined were the nonregenerable and regenerable processes. The nonregenerable produce a calcium sulfite/sulfate waste that is discarded, while in the regenerable the SO_2 in the flue gas is absorbed and subsequently released as SO_2 in the regeneration of absorbent. The SO_2 may be processed further to form sulfuric acid or elemental sulfur.

TABLE 15. WASTE QUANTITIES AND USEABLE BY-PRODUCTS PRODUCED FROM A 500-MW PLANT[a] APPLYING REGENERABLE SO_2 REMOVAL PROCESSES

Case No.	Emissions lb $SO_2/10^6$ Btu	SO_2 Removed by Scrubbing, %	Process	Dry Waste Produced, tons x 10^5/yr[b]	Disposal Area Required, acres[b]	By-Products Produced,[c] tons x 10^5/yr	
						H_2SO_4	S
11	1.2	80	Magnesium Oxide	1.196	151	0.669	0.218
14	1.2	80	Wellman-Lord	1.214	153	0.669	0.218
38	0.6	90	Magnesium oxide	1.201	152	0.753	0.246
41	0.6	90	Wellman-Lord	1.222	154	0.753	0.246

[a] Coal burned: 3.5% sulfur, 12,000 Btu/lb, 14% ash.

Load factor: 50% (4380 hr/yr)

[b] 30-year plant life, waste primarily ash, 30-ft depth

[c] Either H_2SO_4 (100%) or sulfur, but not both.

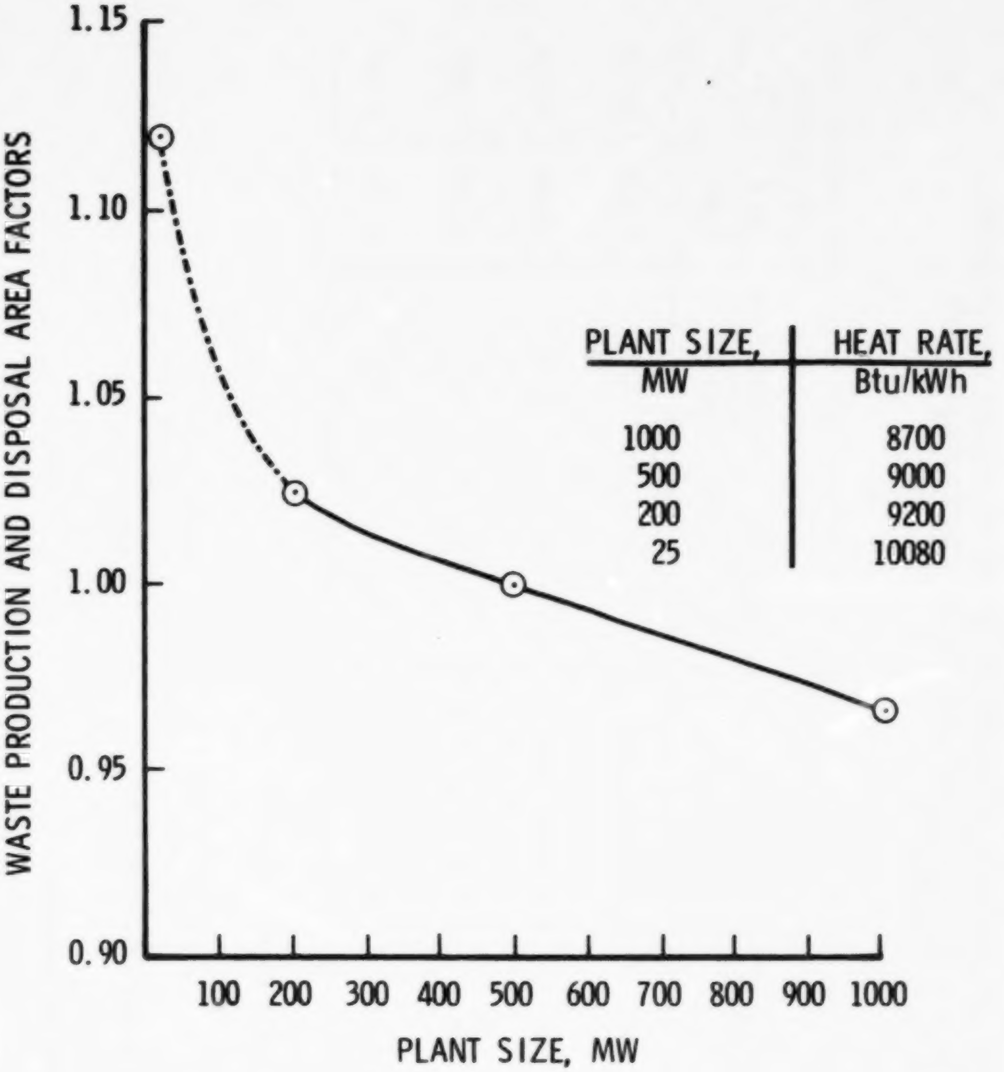


Figure 11. Effect of power plant size and equivalent capacities on the amount of solid wastes produced (includes ash).

The types of nonregenerable processes studied were those using lime and limestone absorbents. The double-alkali process uses a sodium carbonate (Na_2CO_3) absorbent, which is then regenerated by lime. The waste produced is similar to that produced by the direct lime scrubbing except that it contains Na_2CO_3 that is equivalent to the amount of make-up required (3 percent).

Table 16 provides the quantities and composition of waste produced from the five processes as a result of applying the current and alternative federal NSPS standards with 3.5-percent coal. Results for other conditions are provided in Appendix A.

The regenerable processes studied were the magnesium oxide and Wellman-Lord. Typical results are shown in Table 16 and the entire study outputs are included in Appendix A.

3.5.1 Nonregenerable Processes

Use of the limestone wet scrubbing process results in approximately 5 percent more scrubber waste than the lime or double-alkali processes. The slightly lower quantities are primarily the result of the higher lime utilization in the latter two processes (Figure 12). An absorbent utilization of 80 percent was considered typical for limestone, whereas 90 percent was used for the lime process and 95-percent regenerative efficiency for lime in the double-alkali application.

3.5.2 Regenerable Processes

The wastes produced as a result of applying the regenerable processes are approximately 50 percent of those from the nonregenerable. The wastes are primarily ash and are nearly independent of the process. A regenerative-separation efficiency of 95 percent was assumed. Therefore, the waste was assumed to include sulfates of magnesium and sodium equivalent to 5 percent of the magnesium sulfite ($MgSO_3$) or sodium bisulfite ($NaHSO_3$) which was assumed as not being regenerated.

3.6 EFFECTS OF COAL SULFUR ON QUANTITIES OF WASTE PRODUCED

The coals specified for the study (3) were typical. The eastern coals contained 3.5 percent sulfur and high sulfur (7.0 percent), both containing 14 percent ash and a heat content of 12,000 Btu/lb (Table 17). The western coals contained 0.8 percent sulfur[1] and included both high- and

---

[1] The coal sulfur values used are base-case averages. Any coals that may contain these average sulfur contents would meet the NSPS (1.2 lb/10^6 Btu) on the average if subjected to appropriate scrubbing conditions, but may violate it occasionally because of variations in the coal. This factor does not impact the values for sludge quantities derived herein.

TABLE 16. WASTE QUANTITIES AND COMPOSITIONS FROM FIVE FLUE GAS DESULFURIZATION PROCESSES MEETING CURRENT AND ALTERNATIVE NSPS STANDARDS[a]

Case No.	Scrubber Process	Absorbent	Absorbent Consumed[b], tons x 10^4/yr	Absorbent Utilization, %	Absorbent Makeup, %	Nonregenerated Absorbent, %	Total Dry Waste Produced[b], tons x 10^5/yr	Composition of Dry Solids				
								% Ash	% Unreacted $CaCO_3$	% Ca Sulfite	% Ca Sulfate	% Absorbent
1.2 lb $SO_2/10^6$ Btu (80% SO_2 Removal)												
2	Non-Regen	Lime	4.47	90	N/A	N/A	2.234	51.5	3.6	31.1	13.8	N/A
5	Non-Regen	Limestone	8.98	80	N/A	N/A	2.334	49.3	7.7	29.8	13.2	N/A
8	Non-Regen Double Alkali (Lime)	Na_2CO_3	4.25	95	N/A	N/A	2.215	51.9	1.7	31.4	14.0	1.0
11	Regen	Magnesium oxide[c]	0.09	N/A	3	5	1.196	96.2	N/A[d]	N/A	N/A	0.7
14	Regen-Wellman-Lord	Na_2SO_3[c]	0.27	N/A	3	5	1.214	94.7	N/A[d]	N/A	N/A	2.2
90% SO_2 Scrubbing (0.6 lb $SO_2/10^6$ Btu)												
29	Non-Regen	Lime	5.03	90	N/A	N/A	2.369	48.5	3.8	33.0	14.7	N/A
32	Non-Regen	Limestone	10.10	80	N/A	N/A	2.482	46.3	8.1	31.5	14.0	N/A
35	Non-Regen Double Alkali (Lime)	Na_2CO_3	4.76	95	N/A	N/A	2.348	49.0	1.8	33.3	14.8	1.1
38	Regen	Magnesium oxide[g]	0.09	N/A	3	5	1.201	95.7	N/A[e]	N/A	N/A	0.8
41	Regen-Wellman-Lord	Na_2SO_3[g]	0.31	N/A	3	5	1.222	94.1	N/A[e]	N/A	N/A	2.5
0.5 lb $SO_2/10^6$ Btu (85% SO_2 Removal, 40% S Removal by Coal Washing)												
66	Non-Regen	Lime	2.58	90	N/A	N/A	1.319[f]	52.4	3.5	30.5	13.6	N/A
68	Non-Regen	Limestone	5.21	80	N/A	N/A	1.377[f]	50.2	7.6	29.3	13.0	N/A

[a] Coal: 3.5% Sulfur, 12,000 Btu/lb, 14% Ash

[b] 500-MW plant, 50% load factor (4380 hr/yr, waste includes ash)

[c] Potential production: 6.69 x 10^4 tons/yr H_2SO_4 (100%) or 2.18 x 10^4 tons/yr sulfur

[d] Waste also contains 3.1% unregenerated scrubber solid

[e] Waste also contains 3.4% unregenerated scrubber solid

[f] Also 0.409 x 10^5 tons/yr coal wash tailings

[g] Potential production: 7.53 x 10^4 tons/yr H_2SO_4 (100%) or 2.46 x 10^4 tons/yr sulfur

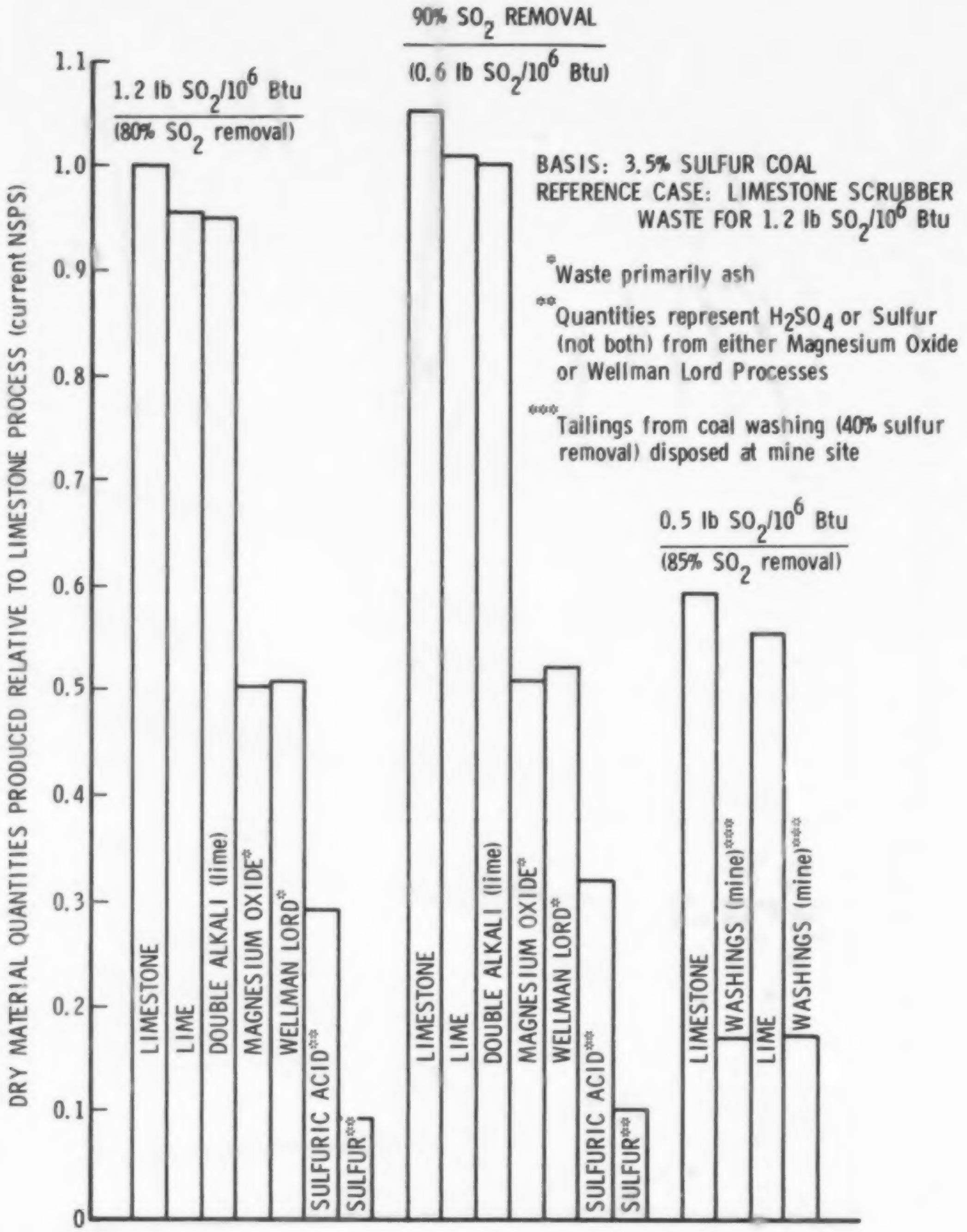


Figure 12. Solid waste, including ash, and useable by-products (nonregenerable and regenerable systems)

TABLE 17. THE EFFECTS OF SULFUR CONTENT ON THE WASTE AND DISPOSAL AREA REQUIRED

Case No.	Coal			Emissions, lb SO_2 per 10^6 Btu	% SO_2 Scrubbed	% Sulfur Removed in Coal Wash	Scrubber[a] Dry Waste Produced, tons x 10^5/yr	Disposal area, acres[b]	Quantity-Volume Ratio[c]
	% S	Btu/lb	% Ash						
27	3.5	12,000	14	1.2	65	40	1.215[d]	158[d]	0.520
							0.409[e]	34	0.175
5	3.5	12,000	14	1.2	80	None	2.334	302	1.000
20	7.0	12,000	14	1.2	90	None	3.813	494	1.634
602	0.8	8,000	6	1.2	25	None	0.942	115	0.404
32	3.5	12,000	14	0.6	90	None	2.482	322	1.000
47	7.0	12,000	14	1.2	90	None	3.813	494	1.536
601	0.8	8,000	6	0.2	90	None	1.196	155	0.482
661	3.5	12,000	14	0.5	91.5	None	2.504	324	1.000
702	7.0	12,000	14	0.5	96	None	3.991	517	1.594
641	0.8	8,000	6	0.5	75	None	1.120	145	0.447
68	3.5	12,000	14	0.5	85	40	1.377[d]	178[d]	0.548
							0.409[e]	34	0.103
711	7.0	12,000	14	0.5	92.5	40	1.789[d]	232[d]	0.714
							0.858[e]	75	0.343

[a] Limestone wet scrubbing, 500-MW plant, 80% absorbent, includes ash. Utilization: 50% load factor,

[b] 30 years, 30-ft depth, scrubber sludge.

[c] Relative to 3.5-percent sulfur, for the appropriate federal NSPS standard group.

[d] Does not include coal wash tailings

[e] **Coal wash tailings**

low-Btu: 10,000 Btu/lb (8-percent ash) and 8,000 Btu/lb (6-percent ash), respectively (Table 18). Several other specific cases were computed to define the sulfur content of western coals capable of meeting the current NSPS emissions standard, and the emissions resulting from burning of eastern low-sulfur coal (anthracite). These cases are summarized in Table 19.

Since sulfur content is the primary variable, its influence on the quantities of waste requiring disposal as a function of both current and more-stringent NSPS federal standards is depicted in Figure 13. Limestone scrubber wastes are represented as typical of nonregenerable processes; the quantities being about 5 percent more than lime or double alkali (Section 3.5). The fraction of wastes relative to 3.5-percent-sulfur coal is shown in Figure 14. Because of the differences in ash and heat content, boiler heat rates, and SO_2 scrubbing requirements, the quantities and disposal area are not directly proportional to the sulfur content. However, as a first approximation, they may be estimated as being linearly related.

The waste quantities resulting from the application of regenerable processes are relatively unaffected for the 3.5- and 7.0-percent sulfur cases studied. The wastes are primarily ash recovered from the combustion of the coal; both coals containing 14 percent sulfur. The slightly higher quantity of wastes for a 7-percent sulfur coal is attributed to the slightly higher quantities of absorbent make-up showing up in the waste because of the larger quantities of SO_2 being scrubbed (the percent absorbent make-up was held constant at 3 percent).

The low-Btu western coal (8000 Btu/lb) was used in all calculations for western coal because it produces only about 5 percent more wastes than the higher (10,000 Btu/lb) coal (Table 18). In general, these two coals represent the high and low extremes expected for western coals. Because of this small difference in quantities produced as a result of burning these extremes of western coal, no attempt was made in the nationwide compilation (Section 3.8) to estimate the fraction of each that may be burned in the future, and the low-Btu coal was used in all of the projections.

In reviewing the effects of the use of western coal, the low-Btu coal (0.8% sulfur, 8000 Btu/lb, 6% ash) produces scrubber waste quantities of 40 to 50 percent of the corresponding limestone-scrubbed 3.5-percent coal (Table 17).

3.7 EFFECTS OF COAL WASHING ON QUANTITIES OF WASTE PRODUCED

The amount of solid waste produced by limestone scrubbing when a 3.5-percent sulfur coal is burned is compared in Table 20 with the solid

TABLE 18. EFFECT OF HIGH- AND LOW-BTU WESTERN COAL ON WASTE GENERATED AND DISPOSAL AREA REQUIRED

A. 90% SO_2 Removal, Wet Limestone Scrubbing, 0.8% Sulfur Coal

Case No.	Coal		Emissions, lb $SO_2/10^6$ Btu	Scrubber Dry Waste[a], tons x 10^5/yr	Disposal Area Req'd[b], acres	Quantity and Volume Factor
	Btu/lb	% Ash				
60	10,000	8	0.16	1.154	150	0.965
601	8,000	6	0.20	1.196	155	1.000

B. Emissions = 1.2 lb $SO_2/10^6$ Btu, Wet Limestone Scrubbing, 0.8% Sulfur Coal

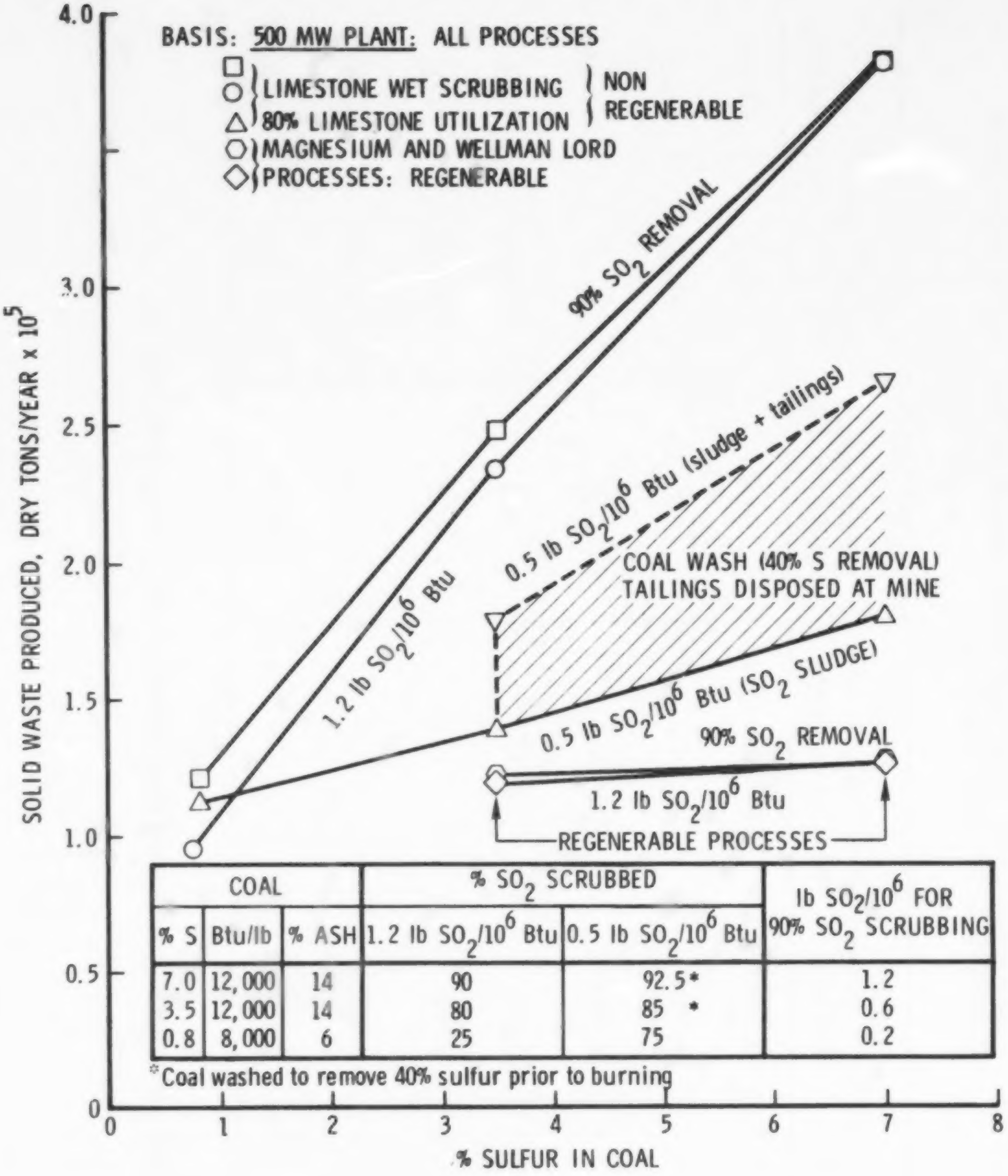
Case No.	Coal		% SO_2 Scrubbed	Scrubber Dry Waste[a], tons x 10^5/yr	Disposal Area Req'd[b], acres	Quantity and Volume Factor
	Btu/lb	% Ash				
603	10,000	8	25	0.890	115	0.945
602	8,000	6	40	0.942	122	1.000

[a] 500-MW plant, 50-percent operating load factor, includes ash.
[b] 50-percent solids, 30 years, 50-percent load factor, 30 ft deep.

TABLE 19. COMPARISON OF THE EMISSIONS AND WASTES PRODUCED FROM BURNING LOW-SULFUR COAL

Source	Coal			% SO_2 Removed By Scrubber	Emissions, lb $SO_2/10^6$ Btu	Scrubber Dry Waste[a], tons x 10^5/yr	Case No.
	% S	Btu/lb	% Ash				
Eastern	0.8	13,500	6	None	1.2	None	22-23
Western	0.6	10,000	8	None	1.2	None	24-25
Western	0.4	8,000	6	None	1.0	None	241-251
Western	0.8	10,000	8	25	1.2	0.890	603
Western	0.8	8,000	6	40	1.2	0.942	602
Western	0.8	10,000	8	90	0.16	1.154	60
Western	0.8	8,000	6	90	0.20	1.196	601

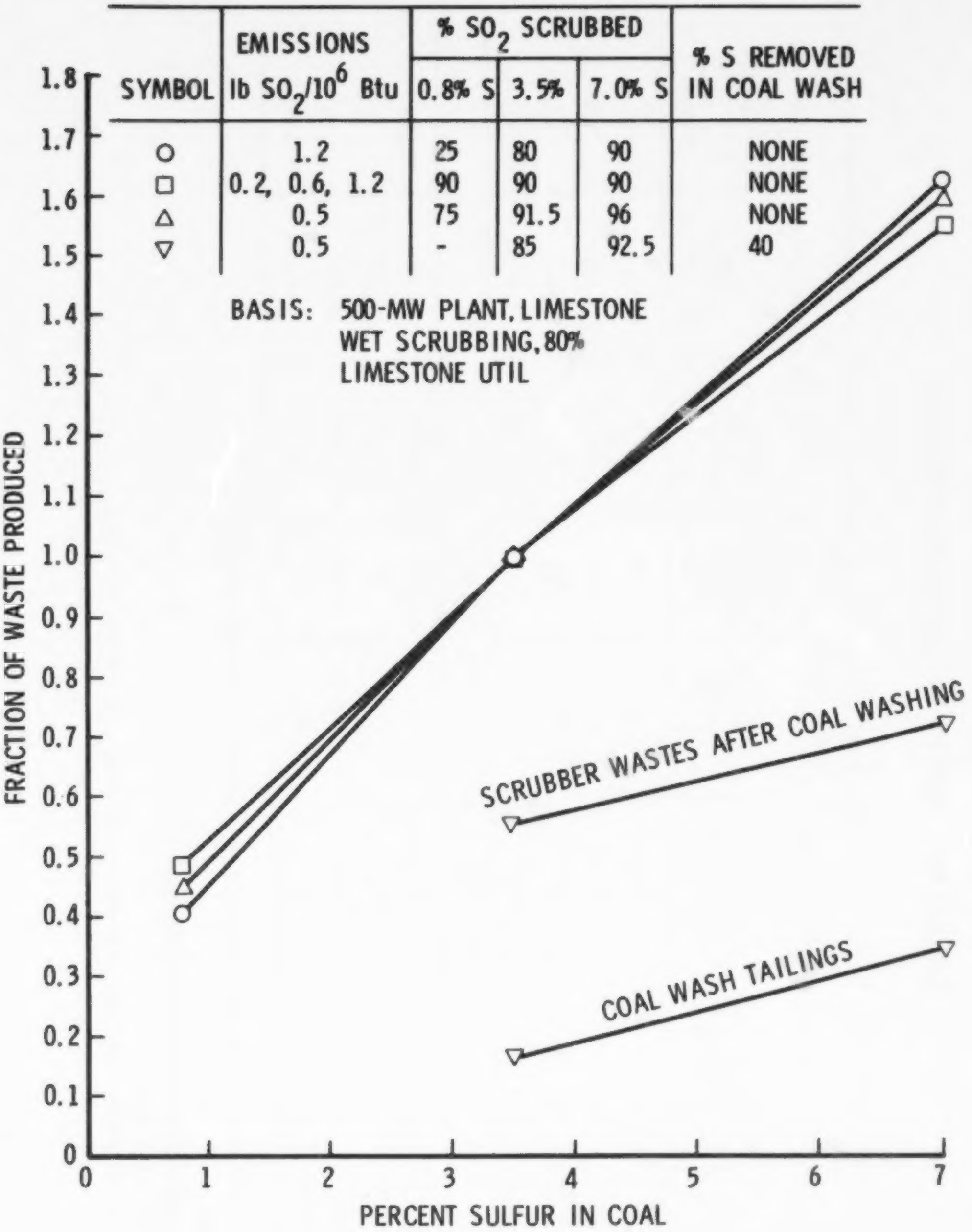
[a] 500-MW plant, 50-percent operating load factor (4380 hr/yr), includes ash



COAL			% SO_2 SCRUBBED		lb $SO_2/10^6$ FOR 90% SO_2 SCRUBBING
% S	Btu/lb	% ASH	1.2 lb $SO_2/10^6$ Btu	0.5 lb $SO_2/10^6$ Btu	
7.0	12,000	14	90	92.5*	1.2
3.5	12,000	14	80	85 *	0.6
0.8	8,000	6	25	75	0.2

*Coal washed to remove 40% sulfur prior to burning

Figure 13. Quantities of waste, including ash, produced by new plants for alternative standards



SYMBOL	EMISSIONS lb $SO_2/10^6$ Btu	% SO_2 SCRUBBED 0.8% S	3.5%	7.0% S	% S REMOVED IN COAL WASH
○	1.2	25	80	90	NONE
□	0.2, 0.6, 1.2	90	90	90	NONE
△	0.5	75	91.5	96	NONE
▽	0.5	-	85	92.5	40

Figure 14. Relative quantities of waste, including ash, produced by new plants as a function of coal sulfur content and alternative NSPS emission standards

TABLE 20. EFFECTS OF COAL WASHING

Case No.	Emissions, lb $SO_2/10^6$ Btu	Sulfur Removed by Washing, %	SO_2 Removed by Scrubbing, %	Scrubber Dry Waste[b] Produced[c], tons x 10^5/yr	Scrubber Waste Disposal Area[d], acres	Coal Wash Tailings (Dry Basis), tons x 10^5/yr	Coal Washed tons x 10^5/yr	Dry Tailings Produced, % of Coal Washed
A. Washing of 3.5% Sulfur Coal[a]								
5	1.2	None	80	2.334	302	None	None	None
27	1.2	40	60	1.215	158	0.409	7.853	5.2
661	0.5	None	91.5	2.504	324	None	None	None
68	0.5	40	85	1.377	178	0.409	7.853	5.2
B. Washing of 7.0% Sulfur Coal[e]								
711	0.5	40	92.5	1.789	232	0.858	8.243	10.4
713	0.5	30	93.5	2.312	300	0.643	8.236	7.8
714	0.5	20	94.5	2.855	370	0.428	8.230	5.2
702	0.5	None	96	3.991	517	None	None	None

[a] 3.5% sulfur, 12,000 Btu/lb, 14% ash. Washed to 2.1% sulfur, 13,200 Btu, 9.2% ash

[b] Ash plus sludge

[c] 50-percent load factor (4380 hr/yr), 500-MW plant

[d] 30-yr plant life, 30-ft depth

[e] 7.0% sulfur, 12,000 Btu/lb, 14% ash. Washed to 4.2% sulfur, 13,200 Btu, 4.0% ash

waste produced by washing the coal first and then scrubbing the flue gas. Only the inorganic fraction, primarily iron pyrite (FeS_2), of the sulfur content can be removed by coal washing, Organic sulfur is an integral part of the coal matrix and cannot be removed by physical separation. Organic sulfur is 30 to 70 percent of the total sulfur for most coals (5). It appears that the maximum sulfur removal that can be achieved by physically washing the coal is limited to about 40 percent.

Although coal washing would not eliminate the need for flue gas scrubbing, the required SO_2 removal could be reduced from 80 to 60 percent for the current standard (1.2 lb $SO_2/10^6$ Btu) and from 91.5 to 85 percent for a standard of 0.5 lb $SO_2/10^6$ Btu. Scrubber sludge and ash at a power plant burning washed coal (40 percent sulfur removed) would be about 56 percent (and wash tailings would be another 16 percent) of the amount of sludge, including ash, from a plant burning unwashed coal.

Iron combined with the sulfur and other ash constituents in the coal are removed by washing (5, 6), reducing the ash in the washed coal considerably; i.e., 14 percent to 9.2 percent for a 3.5-percent sulfur coal (Table 7). Although a loss in heating value is experienced in coal washing, it is accompanied by a greater proportionate loss in weight (inerts) and, therefore, the heat content per pound of washed coal increases. Based on sulfur-reduction data (5), a nominal upgrading of 10 percent was used in the heat content after washing; i.e., the removal of 40 percent sulfur by washing of a 12,000 Btu/lb coal increased its heating value to 13,200 Btu/lb.

To determine the effect of coal washing on meeting the more-stringent emission level of 0.5 lb $SO_2/10^6$ Btu, several cases were run (Figure 15). Decreasing the amount of sulfur removed by washing from 40 percent to 20 percent increases the quantities of scrubber waste by a factor of 1.60 and requires an increase in scrubber efficiency from 92.5 percent to 94.5 percent. If sulfur washing were not used, the scrubber wastes would increase by a factor of 2.23 (over the 40 percent removal), and 96 percent SO_2 removal by scrubbing would be required.

Although coal washing could apparently reduce solid waste (sludge plus ash) at the power plant about 44 percent, consideration must be given to:

a. Disposal of wash tailings (assumed to take place at the mine)

b. Disposal or treatment of the wash process water

c. The increased cost of washed coal over run-of-mine coal

d. The energy required to wash the coal

e. The cost tradeoff of using flue gas desulfurization (FGD) alone versus coal washing plus FGD.

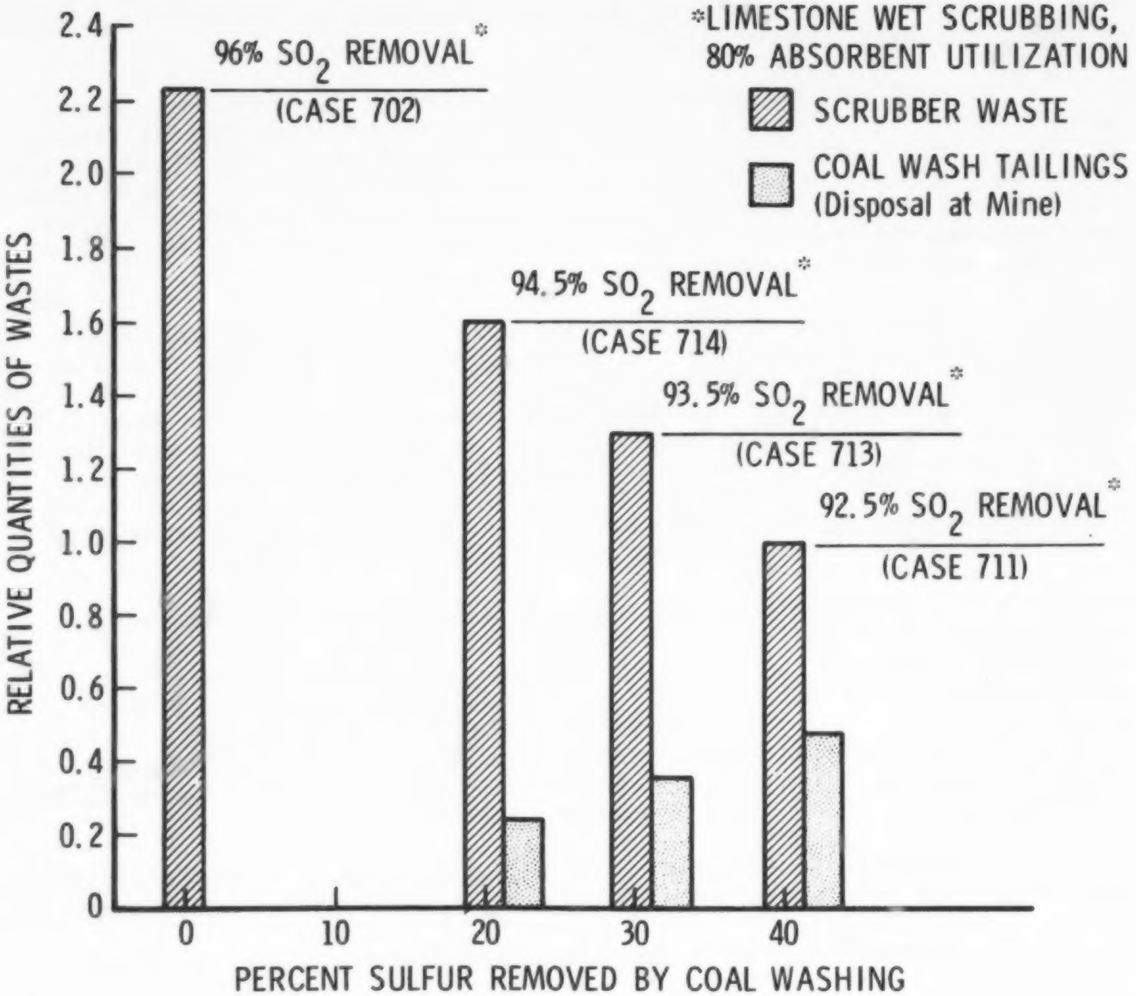


Figure 15. Relative quantities of solid wastes from scrubbing and coal washing from a 500-MW plant burning 7-percent-sulfur coal to meet 0.5 lb $SO_2/10^6$ Btu emissions standard.

These aspects of coal washing are covered in this and other reports prepared as part of the EPA review process.

3.8 NATIONWIDE EFFECTS

The quantities of SO_2 scrubber wastes produced and the land required for disposal in the period 1978-1988 were determined.

The potential production of sulfuric acid or elemental sulfur from regenerable systems, based on assumptions that 5, 25, and 50 percent of the SO_2 scrubbed was converted to sulfuric acid or elemental sulfur, was also defined.

3.8.1 Quantities Produced

Both nonregenerable and regenerable cases were considered. The baseline conditions for the national assessment included the burning of 3.5-percent-sulfur coal in eastern 500-MW plants and 0.8-percent sulfur (8000 Btu/lb) coal in western 500-MW plants. Limestone scrubber waste quantities were used. Other baseline conditions are defined in Tables 21 and 22. The rationale for these conditions have been discussed in Sections 3.1 through 3.7. The effectivity of the more stringent alternatives of 90 percent scrubbing and 0.5 lb SO_2 emissions per 10^6 Btu was 1980 (7). A reference case assuming current federal standards of 1.2 lb SO_2 per 10^6 Btu heat input was also computed through 1988. The annual quantities of scrubber waste produced between 1978 and 1998 are presented in Figure 16.

If all plants employed nonregenerable scrubbing and scrubbed 90 percent of the SO_2, the installations coming on line in 1978 would produce, that year, 5.6 million tons (dry basis) of scrubber wastes; the annual tonnage produced from installations coming on line in 1998 would be 172.8 milion tons (dry basis). The corresponding quantities for the 1.2 and 0.5 lb $SO_2/10^6$ Btu produced in 1998 are 156.2 million and 118.3 million tons (dry basis), respectively. The annual production on a year-by-year basis is tabulated in Appendix B.

The 90-percent scrubbing case, which results in emissions of approximately 0.6 lb $SO_2/10^6$ Btu, produces 12 percent more wastes, which is reflected in correspondingly larger land areas required than the current standards of 1.2 lb $SO_2/10^6$ Btu. The apparent paradox that the 0.5 lb $SO_2/10^6$ Btu condition results not only in lower emissions but also in less total waste than either of the two other cases is the result of the use of coal washing of eastern coal to remove 40 percent of its sulfur.

TABLE 21. BASELINE CONDITIONS FOR NATIONWIDE QUANTIFICATION OF SCRUBBER WASTE DISPOSAL

Plant Size:

500 MW, 30-year life, 50% average load factor (4380 hr/yr)

Coal Burned:

	% S	Btu/lb	% Ash
Eastern	3.5	12,000	14
Western	0.8	8,000	6

Percentage of Plants Burning Eastern Coal:

1978	65%	1979	60%	1980-1998	55%

Scrubber System:

Nonregenerable: Limestone
Regenerable: Magnesium oxide or Wellman-Lord

Application of Alternative NSPS:

a) Current (1.2 lb $SO_2/10^6$ Btu) 1978 through 1998
b) Current through 1979, 90% scrubbing thereafter through 1998
c) Current through 1979, 0.5 lb SO_2 per 10^6 Btu heat input through 1998

Coal Washing:

a) Coal washing to meet 0.5 lb $SO_2/10^6$ Btu applied to eastern (3.5% sulfur) coal only
b) Scrubbing only, and no washing of western coal considered
c) Scrubbing only of eastern coal for current NSPS, and 90% scrubbing cases

Waste Disposal:

Disposal of scrubber wastes and ash (from regenerable systems) considered and presented separately from the disposal of coal wash tailings

Total Annual MW Installed:

See Figure 5 and Appendix B

Percentage of Regenerable Scrubber Systems:

Production of by-products assumed on a parametric basis; i.e., 5%, 25%, and 50% of scrubbed SO_2 converted to sulfuric acid or elemental sulfur

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TABLE 22. SCRUBBER AND COAL WASHING CONDITIONS USED IN THE NATIONWIDE WASTE INVENTORY

Coal				Emissions, lb $SO_2/10^6$ Btu	% SO_2 Scrubbed	% S Removed In Coal Washing	Case No.
Type	% S	Btu/lb	% Ash				
Eastern	3.5	12,000	14	1.2	80	None	5
	3.5	12,000	14	0.6	90	None	32
	3.5	12,000	14	0.5	85	40	68
Western	0.8	8,000	6	1.2	25	None	602
	0.8	8,000	6	0.6	90	None	601
	0.8	8,000	6	0.5	75	None	641

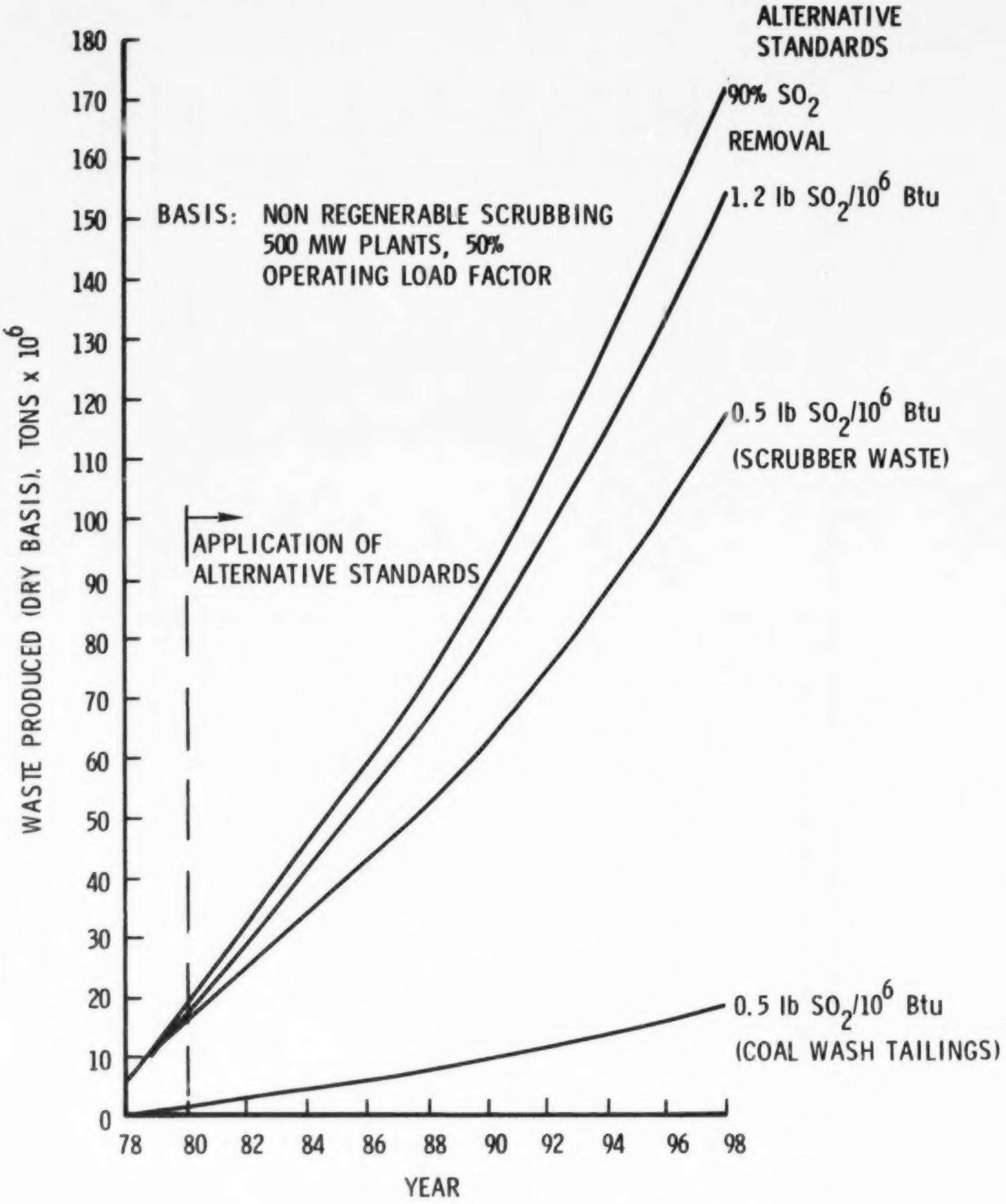

Figure 16. Total annual waste quantities, including ash, produced nationwide by new plants coming on line beginning in 1978

Projections of the number of regenerable scrubber systems reflect a wide range of uncertainty (8). Therefore, an attempt was made to bound the potential application of regenerable systems. Quantities were computed of sulfuric acid (100 percent) or sulfur that could be produced annually, assuming that 5, 25, and 50 percent of the SO_2 scrubbed was accomplished by a regenerable process for years during the 1978 to 1998 interval (Appendix C).

The tonnages of sulfuric acid or elemental sulfur that may be produced annually are summarized in Table 23. As an example, if 90 percent SO_2 removal by scrubbing were initiated in 1980, and if 50 percent of the scrubber systems were regenerable, approximately 1.5 million tons of H_2SO_4 would be produced annually. It was reported (9) that the 1975 nationwide consumption of sulfuric acid was 33 million tons. By considering the 90-percent scrubbing scenario, the 1.5 million tons represents less than 5 percent of the 1975 demand. Furthermore, a 43-million-ton sulfuric acid production capability (east of the Continental Divide) was available in 1975, indicating an unused capacity in excess of 25 percent.

Considering the excess production capacity, and the small annual penetration of the SO_2 abatement acid in the sulfuric acid market, there are many site-specific factors, such as the matching of potential producers and users, that must be considered in the successful marketing of SO_2 abatement acid. This has been under intensive study by EPA and TVA, and the generalized conditions under which beneficial match-ups occur are discussed in Reference 9. A number of improvements to the predictive model developed in that study; its application to specific sites is being considered and more definitive results may be available in the future.

3.8.2 Land Requirements

The land required for disposal of the scrubber waste was also determined. Using the quantities reported in Figure 16, the amount of land required annually to dispose of all sludge production for plants coming on line in any given year is shown, assuming that all the scrubber systems are non-regenerable (Figure 17). More significantly, the total acreage, year-by-year, needed for disposing of the sludge produced by all the new plants coming on line during the study interval of 1978 to 1998 is also shown. This area is shown as the upper three curves in Figure 17; e.g., 223,665 acres for the year 1998 for 90-percent scrubbing for all new plants starting in 1978 versus 7456 acres actually needed in 1998 for plants coming on line that year. (The acreage was determined by assuming a 30-foot depth of waste at the disposal site.)

TABLE 23. COMPUTED ANNUAL QUANTITIES OF SULFURIC ACID OR ELEMENTAL SULFUR FROM NONREGENERABLE SCRUBBER SYSTEMS

	Percent of Total SO_2 Scrubbed (Assumed to be Converted to H_2SO_4 or S)					
	5%		25%		50%	
Year	Sulfuric Acid, tons	Sulfur, tons	Sulfuric Acid, tons	Sulfur, tons	Sulfuric Acid, tons	Sulfur, tons
1.2 lb $SO_2/10^6$ Btu						
1980	112,000	36,000	561,000	183,000	1,122,000	366,000
1983	95,000	31,000	475,000	155,000	951,000	310,000
1988	105,000	34,000	524,000	171,000	1,047,000	342,000
1993	125,000	41,000	627,000	205,000	1,253,000	409,000
1998	172,000	56,000	860,000	281,000	1,720,000	562,000
90% SO_2 Removal						
1980	140,000	46,000	701,000	229,000	1,403,000	458,000
1983	119,000	39,000	597,000	195,000	1,194,000	390,000
1988	132,000	43,000	659,000	215,000	1,319,000	431,000
1993	158,000	52,000	790,000	258,000	1,579,000	516,000
1998	217,000	71,000	1,086,000	354,000	2,172,000	708,000
0.5 lb $SO_2/10^6$ Btu						
1980	82,000	27,000	412,000	134,000	824,000	269,000
1983	70,000	23,000	350,000	114,000	701,000	229,000
1988	77,000	25,000	386,000	126,000	771,000	252,000
1993	92,000	30,000	462,000	151,000	924,000	302,000
1998	127,000	41,000	635,000	207,000	1,270,000	415,000

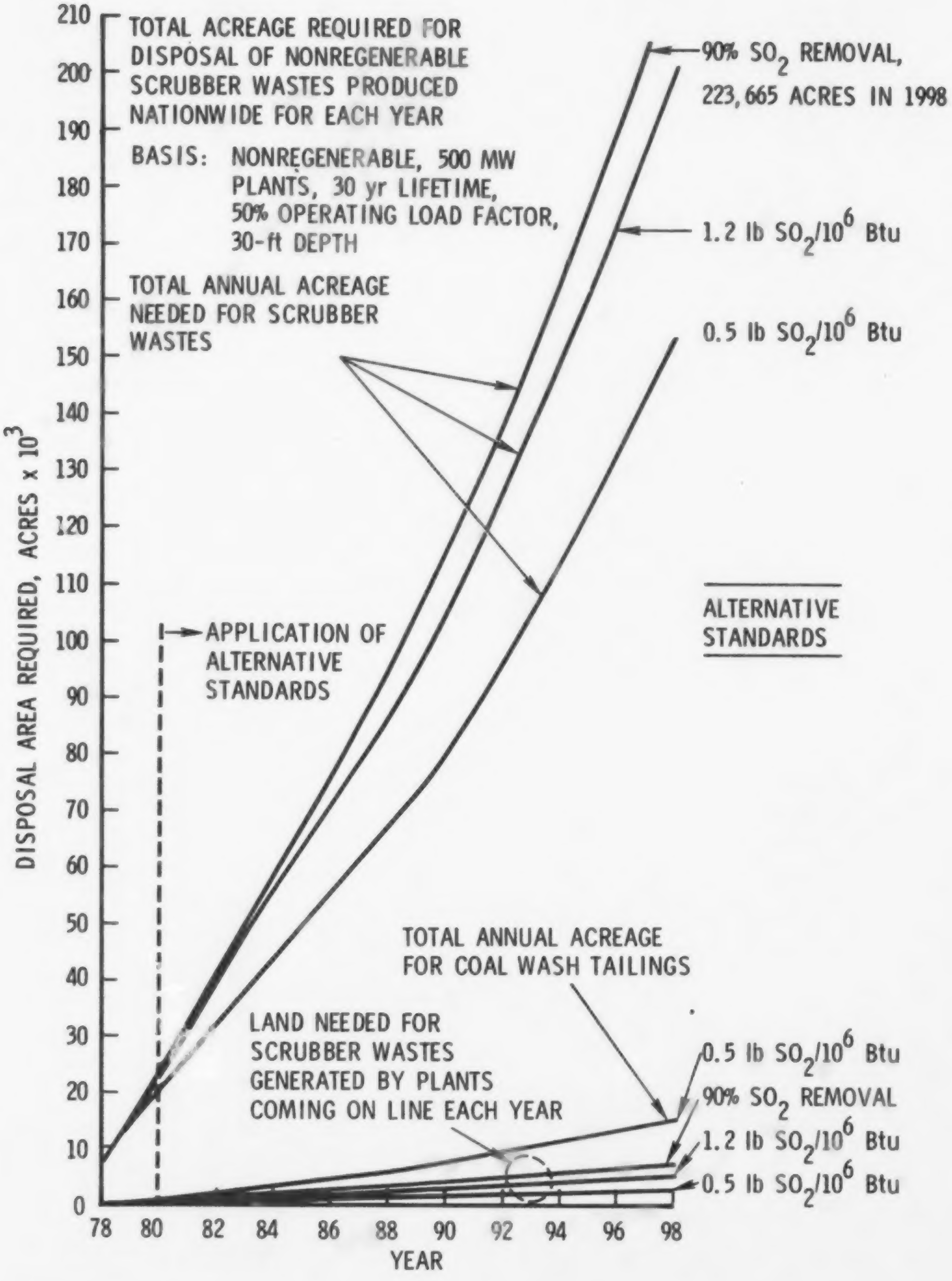

Figure 17. Total acreage required annually for disposal of scrubber wastes, including ash, produced nationwide by new plants coming on line beginning in 1978

SECTION IV

CHARACTERIZATION OF FLUE GAS DESULFURIZATION WASTES

The chemical and physical characteristics relating to the disposal of solid wastes are the result of many parameters related to the control system process, its design, and operating variables. The properties of any liquid-solid mixture are dependent upon the characteristics of both the liquid and the solid constituents as well as the interaction between them. The nonregenerable flue gas desulfurization (FGD) wastes contain four principal crystalline phases: calcium sulfite, calcium sulfate, fly ash, and unreacted limestone or precipitated calcium carbonate. Wastes from the double-alkali process also contain sodium carbonate (absorbent). These solid phases exist as fine particulates suspended in an aqueous liquor that is usually saturated with ions of these solids. In addition, sodium chloride or calcium chloride is also present as a dissolved salt.

The relative amounts of each of the solid crystalline phases are dependent upon many system design parameters and include (a) the sulfur content of the coal and the efficiency of scrubbing SO_2, (b) the fly ash in the flue gas entering the scrubber and the fly ash removal efficiency of the system, (c) the stoichiometric ratio of reactants relative to the sulfur content and the reactant utilization efficiency, and (d) the amount of oxidation of the sulfur products that takes place in the system. In addition, each crystalline phase and the characteristic of each phase will have some influence on the behavior of the waste.

Complete characterization and separation of the effects of the control system design and operating variables on the properties of the wastes would require considerable time and expense inasmuch as it would require many different, large developmental facilities dedicated to the attainment of these correlations. To achieve a reasonable balance between idealized programs and the limitations of time and resources, several approaches have been taken. Typical of these are the following:

a. A systematic evaluation of the effects of a number of operating variables on solid waste properties is being conducted by TVA at the Shawnee 10-MW (equivalent) scrubber test facility in a program sponsored by EPA. A number of tests in the mist elimination, magnesium oxide, and factorial testing program have been conducted using the venturi-spray tower scrubber and the turbulent

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contact absorber with lime and limestone absorbents. The effects on waste properties as a function of liquid-to-gas ratios, fly ash, and degree of gypsum saturation are being analyzed.

b. In other tests (10), the effects on solids characteristics resulting from variable loads, maximum oxidation, fly ash-free, SO_2 removal efficiency, and reliability are being determined.

c. Another approach taken by EPA contractors, and others, consists of taking discrete waste samples from operating plants, noting the conditions under which they were formed, and relating them to the properties of the waste.

This section attempts to bring together results from the above types of evaluations and to discern trends and draw conclusions within the approaches outlined.

4.1 EFFECTS OF CONTROL SYSTEM PROCESSES

Both scrubber design and operating system variables are expected to affect solid waste characteristics. Waste property data included in this section have been reported in varying degrees from individual lime, limestone, and double alkali systems: venturi-spray tower, turbulent contact absorber, marble bed absorber, bubble cap tower, and flooded disc absorber (Table 24). Sizes have ranged from approximately 0.1 MWe to a 410-MWe unit. Except for the systematic testing by TVA at the Shawnee 10-MWe test facility to determine the effects of operating parameters on waste properties, described in this section, the operating conditions and coal in use at the time of sampling generally comprise the maximum data base on those effects. Some data on start-up and scrubber loop characterization are also available.

4.1.1 Design Parameters

After a review of the available data, the highly variable characteristics of the wastes specifically relatable to individual scrubber system design could not be discerned. However, the effects of the basic control system itself (i.e., lime, limestone, or double alkali) have been observed, and these are discussed according to available data in Section 4.2 (chemical characteristics) and Section 4.3 (physical characteristics).

4.1.2 Operating Parameters

The plant operating conditions identified by TVA (10) to be most closely related to variations in the properties of solids are the liquid-to-gas ratios, the presence of fly ash, and the degree of gypsum supersaturation. At this time detailed results have not been reported. TVA has stated that, in many cases, no firm conclusions can be drawn between data trends and process

TABLE 24. FLUE GAS DESULFURIZATION SYSTEMS SAMPLED AS DATA BASE

Power Plant	Scrubber System	Scrubbing Capacity, MW Equivalent	Coal Source	Absorbent
EPA/TVA Shawnee Steam Plant	Venturi and spray tower, prototype	10	Eastern	Lime
EPA/TVA Shawnee Steam Plant	Turbulent contact absorber, prototype	10	Eastern	Limestone
Arizona Public Service Company, Cholla Power Plant	Flooded-disc scrubber, wetted-film absorber	120	Western	Limestone, fly ash
Duquesne Light Company, Phillips Power Station	Single- and dual-stage venturi	410	Eastern	Lime
General Motors Corporation, Chevrolet-Parma Power Plant	Double-alkali bubble-cap tower	32	Eastern	Lime, soda ash
Southern California Edison, Mohave Generating Station	Turbulent contact absorber, pilot plant	<1	Western	Limestone
Utah Power and Light Company, Gadsby Station	Double-alkali, venturi and mobile bed	<1	Western	Lime, soda ash
Gulf Power Co., Plant Scholz	Venturi and spray tower	10	Eastern	Soda ash, lime
Louisville Gas and Electric, Paddy's Run Station	Marble bed absorber	65	Eastern	Carbide, lime
EPA, Pilot Plant, RTP, NC.	Two-stage scrubber	≈0.1	Simulated eastern	Limestone

variables. In other cases, definite relationships were noted to be emerging, but these were still subject to further refinement or modification upon completion of the program and, therefore, not available during the preparation of this report.

Other results (11, 12) were based on chemical analyses of samples from ten different scrubbers having capacities ranging from 1 to 125 MW equivalent. They were reported as a function of location within a scrubber circuit as well as a function of time, pH, absorbent, and coal composition. Results included the effects of time, pH, and absorbent in scrubber-liquor trace-element concentration, as well as the effects of coal composition on solid and liquid waste trace-element concentration. It was found that:

a. The concentration of major chemical species increases with time from start-up until a steady-state condition is reached for all species. Trace element concentrations reach steady-state rapidly and are not affected by the steady-state conditions of the major species.

b. The system pH is effective in controlling trace element species only within a defined system where major process parameters are controlled.

c. Western coals in general tend to have lower trace metal contents than eastern coals, and significantly lower concentrations of arsenic, cadmium, mercury, and zinc.

d. The major portion of trace metals found in the sludge liquor originates from leaching of the fly ash during the more acid portion of the scrubbing cycle. The contribution made by the process waters is insignificant relative to the contribution from coal, and, in most cases, the contribution of the absorbent is slight.

e. The trace element content of sludge solids and liquors is directly related to the trace element content in the coal (Figures 18 and 19). The concentration of the trace elements (controlled by drinking water criteria) in the sludge solids was approximately the same as in the coal (11). This relationship was applicable over a range of concentrations of three orders of magnitude. The concentration of the same elements in the waste liquor was about 1/100 of the concentration in the coal.

4.2 CHEMICAL CHARACTERISTICS

Chemical properties of scrubber waste and solids liquors and FGD waste leachates have been reported (13). More data are becoming available on FGD waste leaching characteristics as EPA-sponsored programs progress and will be used to provide new information or augment existing data.

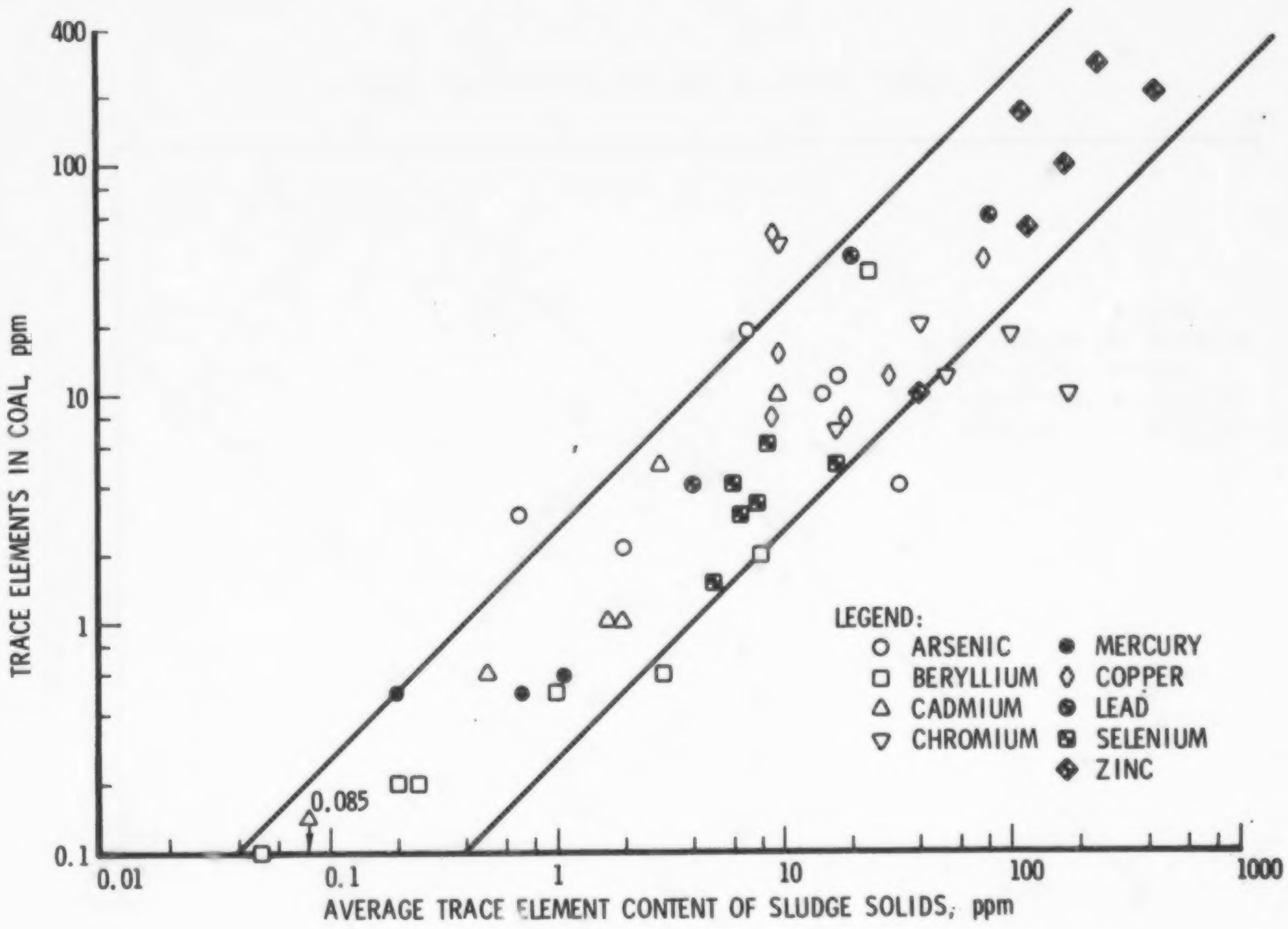

Figure 18. Average trace element content of sludge solids.

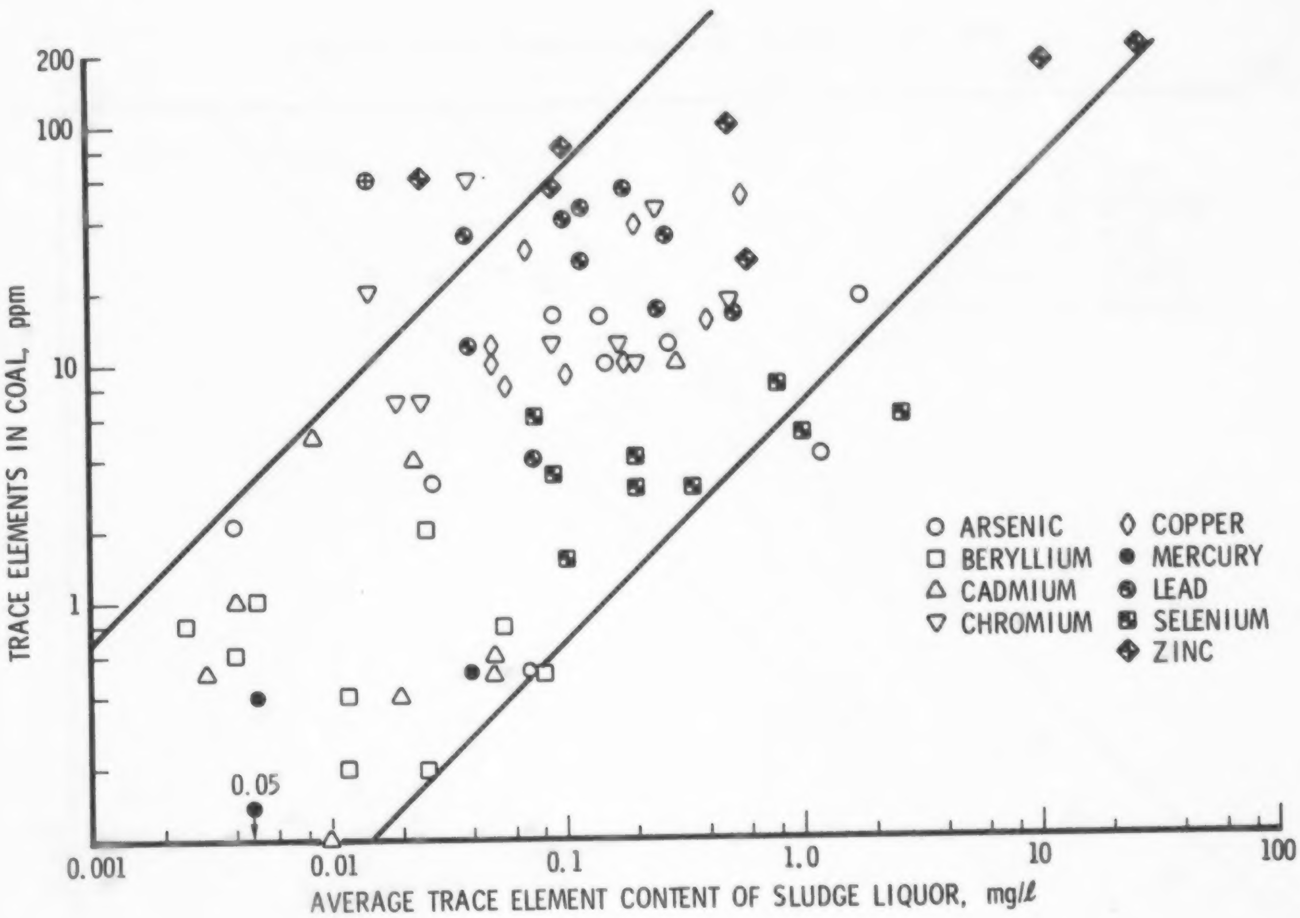

Figure 19. Average trace element content of sludge liquor.

Chemical, x-ray, and scanning electron microscope analyses of the solid fractions of the wastes have continued to show the uniqueness of the characteristics, with properties affected by coal composition and scrubber operating variables such as pH, liquid-to-gas ratio, and hold-tank residence times (10).

The effect of process variables on the concentration of chemical constituents was reported (11) as a function of the location within a scrubber circuit, as well as a function of the scrubber process itself, i. e., lime, limestone, and double alkali.

The concentrations of major chemical species and trace elements in FGD wastes decrease as the sludge passes from the scrubber to the disposal point. However, the constituents are affected differently as they progress through the scrubbing process. An indication of the end-to-end (scrubber stage to disposal stream) changes for the concentrations of various constituents is shown for the limestone process in Table 25 by relating the constituent concentrations of liquors in the scrubber to those in the disposal material.

The range of concentrations of constituents found in 10 different eastern and western scrubber liquors is shown in Table 26. A summary (11) of the net changes in the liquor stream between the initial (scrubber) stage and the final stage (disposal stream) for lime, limestone, and double alkali is shown in Table 27. Analyses of liquid and solid constituents are tabulated in Appendix D.

TABLE 25. RELATIVE CHANGE IN CONCENTRATION OF CONSTITUENTS IN THE SCRUBBER CIRCUIT LIQUOR: LIMESTONE PROCESS

Constituent	Direction of Change	Change from Scrubber Stage to Disposal Stream[a]
Calcium	Decrease	30 to 40%
Chloride	Decrease	20%
Sulfite	Decrease	>99%
Sulfate	Decrease	10%
Trace metals	Decrease	10 to 20%
pH	Increase	2 units

[a] Reference 16

TABLE 26. CHANGE OF CONCENTRATIONS OF CHEMICAL CONSTITUENTS IN FGD SLUDGES FROM LIME, LIMESTONE, AND DOUBLE-ALKALI SYSTEMS

Scrubber Constituent	Sludge Concentration Range[a]	
	Liquor, mg/l (except pH)[b]	Solid, mg/kg[c]
Aluminum	0.03 - 2.0	- -
Arsenic	<0.004 - 1.8	0.6 - 52
Beryllium	<0.002 - 0.18	0.05 - 6
Cadmium	0.004 - 0.11	0.08 - 4
Calcium	180 - 2600	105,000 - 268,000
Chromium	0.015 - 0.5	10 - 250
Copper	<0.002 - 0.56	8 - 76
Lead	0.01 - 0.52	0.23 - 21
Magnesium	4.0 - 2750	- -
Mercury	0.0004 - 0.07	0.001 - 5
Potassium	5.9 - 100	- -
Selenium	<0.0006 - 2.7	2 -17
Sodium	10.0 - 29,000	- - 48,000
Zinc	0.01 - 0.59	45 - 430
Chloride	420 - 33,000	- - 9,000
Fluoride	0.6 - 58	- -
Sulfate	600 - 35,000	35,000 - 473,000
Sulfite	0.9 - 3500	1600 - 302,000
Chemical oxygen demand	<1 - 390	- -
Total dissolved solids	2800 - 92,500	- -
pH	4.3 - 12.7	- -

[a] Data derived from Appendix D.

[b] Liquor analyses were conducted on 13 samples from seven power plants burning eastern or western coal and using lime, limestone, or double-alkali absorbents.

[c] Solids analyses were conducted on 6 samples from six power plants burning eastern or western coal and using lime, limestone, or double-alkali scrubbing processes.

TABLE 27. NET CHANGE IN SCRUBBER LIQUOR COMPOSITION OF MAJOR, MINOR, AND TRACE CONSTITUENTS BETWEEN INITIAL AND FINAL STAGES IN SCRUBBER SYSTEM

Constituent	Limestone[a]			Lime[a]			Double Alkali[a]		
	Increase	Decrease	No Significant Change (<20%)	Increase	Decrease	No Significant Change (<20%)	Increase	Decrease	No Significant Change (<20%)
Aluminum (Al)		XXX			XX	X			
Antimony (Sb)		X			X	XX			
Arsenic (As)	X	X	XXX		XXX	X			X
Beryllium (Be)		XX	XXX			XXXX			X
Boron (B)					X				
Cadmium (Cd)		X	XXX		XX	XX			X
Calcium (Ca)		XXXX			XX	XX			X
Chromium (Cr)	XX	X	XX	X		XX			X
Cobalt (Co)		X				XX			
Copper (Cu)	XX		XXX	X	XX				X
Iron (Fe)		X			XXX				
Lead (Pb)	XX	XX	X			XXXX			X
Magnesium (Mg)	X	X	XX		X	XX			
Manganese (Mn)				X	X				
Mercury (Hg)		XX				XXX		X	
Nickel (Ni)		X			X	X			
Potassium (K)	XXX			XX			X		
Selenium (Se)	XX		XX		X	XXX		X	
Silicon (Si)					XXX				
Silver (Ag)		X			XX	X			
Sodium (Na)			XXXX			XXX			
Zinc (Zn)	X	XXX	X		XXX	X	X		
Chloride (Cl)		XXXX			XX	XX	X		
Fluoride (F)	XX		X	XX		XX			X
Sulfate (SO_4)			XXXX		XX	XX	X		
Sulfite (SO_3)		XXXX			XXX			X	
TDS		XXXX			XX	X	X		
pH	XXXX			XXXX					X

[a] Each "X" represents a separate sample set.

4.2.1 Major Chemical Constituents

The composition of the solids fraction of wastes sampled was determined by chemical means and is presented in Table 28.

In the sludge solids, gypsum and calcium sulfite hemihydrate are the principal sulfur products, together with a broad range of fly ash contents (3-60%) resulting from either separate or simultaneous fly ash collection. Several soluble phases are present as a consequence of salt formation during drying of occluded water. The presence of limestone in all samples is a consequence of both unreacted limestone absorbent and carbonate formation by absorption of carbon dioxide from the atmosphere. The wide range in composition for each of the major solid constituents reflects the various design differences that exist among scrubber systems. Systems having high-efficiency fly ash collection facilities upstream of the scrubber are contrasted sharply with those systems having less efficient collection methods. The calcium sulfate content of the sludge reflects in each case the capability of the calcium sulfite to be oxidized, this reaction usually occurring in the scrubber or reaction tank.

Verification of the constituents and their crystalline morphology or definition of other characteristics such as size and shape is generally obtained by x-ray diffraction or scanning electron microscope techniques.

Concentrations of major chemical species in sludge liquors depend primarily on oxidation conditions in the scrubber and fly ash collection methods. Generally the total dissolved solids (TDS) content does not exceed 10,000 mg/ℓ, except during start-up and under exceptional operating conditions, and for double-alkali systems which generally operate at a much higher TDS content. The chloride concentration in the liquor depends primarily on the chloride content of the coal.

4.2.2 Minor Chemical Constituents

The concentration of trace elements in system liquors tends to range between 0.01 and 1 mg/ℓ for all elements except mercury, which is about one-tenth that of other trace elements. In the sludge solids, concentrations of trace elements are approximately 100 times greater than that of the liquor.

Generally, the concentrations of trace elements in scrubber liquors from the limestone, lime, and double-alkali processes were highest in the limestone system, intermediate in the lime, and lowest in the double-alkali process; however, the actual concentration differences attributable to the process are not considered significant relative tc their pollutional potential. The data indicate that the concentration effect is a consequence of pH within the respective scrubbers and, as such, is not a pollution control mechanism.

TABLE 28. PHASE COMPOSITION OF FGD WASTE SOLIDS IN WEIGHT PERCENT[a]

ATOMIC FORMULA	TVA SHAWNEE LIMESTONE, 2/1/73	TVA SHAWNEE LIMESTONE, 7/12/73	TVA SHAWNEE LIMESTONE, 6/15/74	TVA SHAWNEE LIME, 3/19/74	SCE MOHAVE LIMESTONE, 3/30/73	GM PARMA DOUBLE ALKALI, 7/17/74	APS CHOLLA LIMESTONE, 4/1/74	DLC PHILLIPS LIME, 6/17/74	UPL GADSBY DOUBLE ALKALI, 8/9/74	SHAWNEE LIME, 9/8/76	LG&E LIME	GULF-SCHOLZ 6/20/76
$CaSO_4 \cdot 2H_2O$	21.9	15.4	31.2	6.3	84.6	48.3	17.3	19.0	63.8	19.4	15.1	15.3
$CaSO_3 \cdot 1/2H_2O$	18.5	21.4	21.8	48.8	8.0	12.9	10.8	12.9	0.2	69.2	37.4	68.1
$CaSO_4 \cdot 1/2H_2O$						19.2						
$CaCO_3$	38.7	20.2	4.5	2.5	6.3	7.7	2.5	0.2	10.8	10.3	29.5[a]	10.1
$MgSO_4 \cdot 6H_2O$	4.6	3.7	1.9	1.9								
$Na_2SO_4 \cdot 7H_2O$						6.9					7.8	
NaCl					1.5							
$CaSO_4$[b]									17.7			
FLY ASH	20.1	40.9	40.1	40.5	3.0	7.4	58.7	59.7	~8.6	<1.0	12.4[a]	<1.0
OTHER							10.7[c]	8.2[c]			3.5[d]	
TOTAL	103.8	101.6	99.5	100.0	103.4	102.4	100.0	100.0	101.1	99.9	105.7	94.5

[a] The carbide lime used as absorbent is an acetylene manufacturing plant waste by-product and is reported to contain 2-2 1/2 percent silica and 3-8 percent $CaCO_3$

[b] Phase not explicitly measured; presence deduced from x-ray study

[c] Soluble salt, phase not determined; quantity by difference

[d] Carbon

An evaluation was also reported (11) of the trace element content in the system liquor at various positions in the scrubber process. Chemical analyses indicated that the system liquor pH increased and trace element content decreased en route from the scrubber to the disposal site. The decrease in trace elements may be interpreted as a response to system pH, or a response to the changes taking place in the concentration of major chemical species. The in-process analyses revealed, for the major species, that a rapid oxidation of sulfite ion and the precipitation of calcium sulfate also takes place en route to the disposal site. The trace element content in the liquor may be decreasing by precipitation in response to decreasing ionic strength, by coprecipitation resulting from the scavenging action of the calcium sulfate, by absorption onto newly created crystal surfaces of the calcium sulfate phase, or by the pH changes previously discussed.

There is a direct relationship between the trace elements in sludge and those in coal (Section 4. 1. 2). The correlations that exist between trace elements in coal and the trace elements in fly ash lead to the conclusion that fly ash particles are the principal source of these trace elements in the sludge for all but the most volatile elemental species (e. g., mercury and selenium) that are scrubbed from flue gases.

Western coal, having lower concentrations of arsenic, cadmium, mercury, and zinc than eastern coal, produces sludges having lower concentrations of these elements.

An interesting series of experiments was reported (12) on the effect of collecting fly ash upstream of the scrubber on scrubber liquor trace element concentrations. Previously reported analyses for trace elements in liquors and leaches (Section 4. 1. 2) are only for sludges produced by scrubbing flue gas that contained some or all of the fly ash. Therefore, to determine whether the trace elements resulted from the scrubbing of fly ash, sludge was analyzed from scrubbing operations in which fly ash was removed from the flue gas ahead of the scrubber. In addition, leaching tests were made with sludge/fly ash mixtures prepared by the addition of fly ash to ash-free FGD sludge and with fly ash alone, using leaching water with pH's ranging from 4 to 9. An attempt was made to correlate the magnitude of the measured trace element concentrations in sludge liquors and leachates with fly ash, pH, and conditions of scrubbing or leaching.

The results of the fly ash equilibrium/solubilization tests do not substantiate that low-pH scrubbing of fly ash will produce higher levels of all trace elements in sludge liquors. Also, it was reported that the concentrations of trace elements in the ash-free sludge liquor were comparable either to the lowest levels or to the median levels observed for the liquors from sludge containing fly ash. Leachates of the ash-free lime sludge and the sludge mixed with 40 percent fly ash showed comparable concentration levels of the trace elements. Therefore, it is probable that removal of fly ash ahead of the scrubber will not significantly reduce the concentration levels of most trace elements in the sludge liquors and leachates. Also, examination with the scanning electron microscope of the solid phases of each of the supposedly ash-free sludges showed the presence of some fly ash particles. Therefore, it is probable that the finest fly ash particles, i. e., those with the largest relative surface area and, therefore, the highest leachability, are carried past the separators by the flue gas. This may explain why the trace elements were found in comparable concentrations in the liquors of ash-free sludge and sludge containing fly ash.

4.2.3 Leaching Characteristics

The concentration of the major species in leachate, i. e., sulfate and chloride ions, and total dissolved solids (TDS), decreases rapidly during the first three pore (void) volume displacements (PVD) where about 90 percent of the decrease takes place relative to the fifth pore volume (11). The concentrations at the 50th PVD are approximately the same as at the 5th PVD (see Figures 20 and 21). Major species and trace elements existing at high concentration (>0.1 mg/ℓ) are shown, from which typical behavior can be observed. For most trace elements existing in low concentrations in the liquor, the concentration in the leachate dropped below the detection limit of the test method after only a few pore volume displacements. Some elements showed a sustaining concentration level after the initial pore flushing, as was seen for major species, while others did not. No clear pattern is evident for trace elements except that continued flushing of a given sample tends to quickly reduce the concentration to less than 10 percent of its original value.

For untreated wastes, the pH of the leaching solution showed no discernible effect on the leachate except for the trace elements lead and zinc, which were leached more readily by acidic conditions. Solubility testing of fly ash showed only cadmium, copper, and lead concentrations higher at an acidic pH of 4.0 than at 7.0.

Untreated wastes were leached under both aerobic and anaerobic conditions (11). The anaerobic conditions simulated the effect of wastes with a high affinity for oxygen (as is the case for sulfite sludges) for conditions simulating the lower layers of wastes in a covered landfill. The results showed that, at any given displacement volume, a greater drop in concentrations of major species in the leachate occurs with anaerobic conditions than with aerobic conditions. At the fifth pore volume for aerobic conditions, the sulfate concentrations reached 1100 to 1300 mg/ℓ, and chloride 95 to 130 mg/ℓ, irrespective of the initial concentration in the mother liquor. The corresponding concentrations for the anaerobic conditions are 900 to 1100 mg/ℓ and 65 to 70 mg/ℓ for sulfate and chloride ion concentrations, respectively. When a similar comparison was made for the trace elements, no clear trend was observed except for lead where it was consistently and significantly higher (at the 50th PVD) when leached under anaerobic conditions.

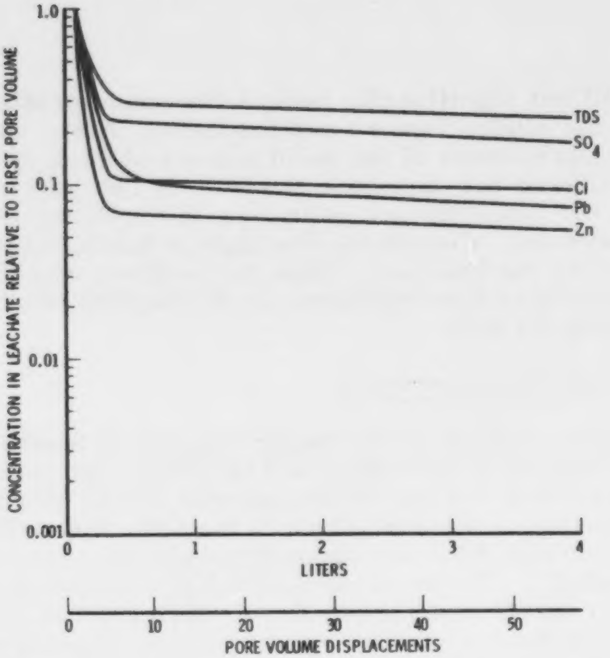

Figure 20. Analysis of leachate from TVA Shawnee limestone sludge: aerobic conditions.

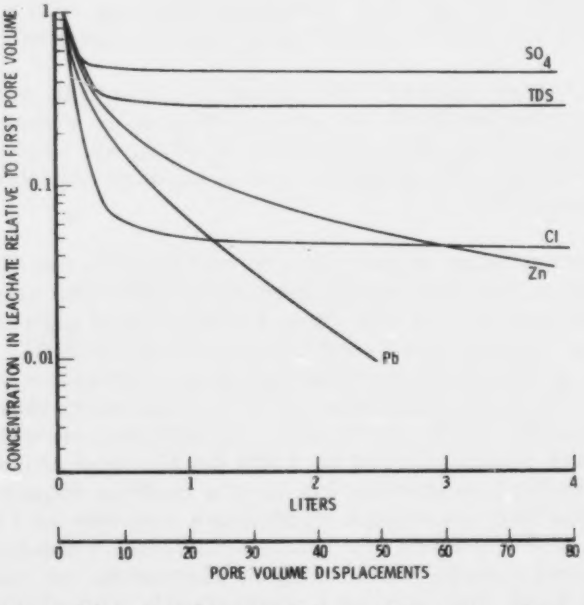

Figure 21. Analysis of leachate from Duquesne Phillips sludge: aerobic conditions.

4.3 Physical Characteristics

The physical properties considered in the disposal of wastes include: bulk density, water retention characteristics, bearing strength, permeability, and viscosity of the waste slurry. The latter is important in the transport of the waste to its disposal site, and the others affect the weight and volume of the disposal material as well as the suitability of the waste as a load bearing material and deterrent to seepage in a disposal site.

The physical properties of the moisture-containing wastes are dependent upon the characteristics of both the liquid and the solid constituents as well as the interaction between them. The lime and limestone scrubber wastes contain four principal crystalline phases: calcium sulfite, calcium sulfate, fly ash, and unreacted limestone or precipitated calcium carbonate. In addition, double-alkali wastes contain Na_2CO_3 absorbent carried over from the absorbent regeneration process. These solid phases exist as fine particulates suspended in an aqueous liquor. In addition, chloride ions originating from various sources, including make-up water and coal, are also present.

Although data to quantify the amount of each of the solid crystalline phases from the various sources are not available, the relative amounts can be described as being dependent upon numerous system design and operating parameters and include (a) the sulfur content of the coal and the efficiency of SO_2 removal, (b) the fly ash in the flue gas entering the scrubber and the fly ash removal efficiency of the system, (c) the stoichiometric ratio of reactants added relative to the sulfur content and the absorbent utilization efficiency, and (d) the amount of oxidation of the sulfur products that takes place in the system. In addition, each crystalline phase and the characteristics of each phase will have some influence on the behavior of the waste. These characteristics were discussed in Section 4.2.

4.3.1 Water Retention and Bulk Density

The water retention and, conversely, the dewatering characteristics, of flue gas desulfurization (FGD) wastes are important to the various disposal techniques in that they affect the volume of the disposal basin, the waste handling methods, and the condition of the wastes in their final disposal state. The water returned to the scrubbing system reduces the need for make-up water and also reduces the pollution potential associated with the liquid phase at the disposal site. Bulk density is then a consequence of the dewatering characteristics of a waste.

The effectiveness of the dewatering method and the ability of a sludge to be dewatered is a function of a number of solid characteristics including the size and distribution of particles, and the crystalline structure of the particles, which are a function of the system as well as its operating parameters, including the type of coals. Generally, four dewatering methods are used: settling, settling by free drainage, vacuum filtration, and centrifugation; the results are almost exclusively based on laboratory experiments.

The effectiveness of a dewatering operation, i.e., the relative quantity of water that remains with the solid after performing the dewatering operation, is characterized by the wet bulk density of a sludge.

The sludges with the best overall dewatering characteristics are those with coarse particle size distributions, generally those produced by the limestone scrubber systems. The double-alkali systems produce the finest particle size distributions and have the poorest dewatering characteristics.

The highest density is obtained principally by vacuum assisted filtration in most sludges and by centrifugation in a few cases. In all cases, there are relatively small density differences resulting from these two dewatering methods.

In most sludges, there is very little difference in the density when dewatered by settling or settling followed by free drainage, although the latter always exhibits higher densities due to the lower retention from its free draining condition. While free draining may not produce a significant improvement in bulk density, the slight gain coupled with its associated solids content in some cases may significantly affect its load bearing strength, as discussed in Section 4.3.2.

Generally, the wet bulk density ranges from a low of approximately 1.48 g/cm^3 (92 pcf), for settled sludges, to a high of 1.76 g/cm^3 (110 pcf) for vacuum filtered (see Table 29). Drained and centrifuged values were intermediate to these extremes, with drained being slightly higher than the settled and centrifuged slightly lower than the filtered. These values were obtained under laboratory conditions and may not be representative of results using commercial equipment. However, it is expected that the defined trends will apply.

No general relationship has yet been determined between slurry solids content and settling rates because of the strong influence of solids morphology on this property.

An interesting phenomenon was reported (12) with freely drained Shawnee lime sludge to which fly ash had been added. The solids content was adjusted to approximately 25 percent to simulate clarifier underflow. When poured into a test container, the coarser fly ash particles (typically 50 μm in diameter) settled more rapidly than the sulfur-phase particles (typically 20 μm in diameter) and formed a fly ash layer on the filter paper used as a retainer. Although supernate drained through the paper as in all other cases

TABLE 29. WATER RETENTION AND BULK DENSITY CHARACTERISTICS (10)

Scrubber System	Dewatering Method							
	Settled		Settled and Drained		Centrifuged		Vacuum Filtered	
	Percent Solids	Density, g/cc	Percent Solids	Density, g/cc	Percent Solids	Density, g/cc	Percent Solids	Density, g/cc
Lime	40-48	1.34-1.40	43-53	1.36-1.50	50-57	1.39-1.52	56-57	1.48-1.54
Limestone	47-67	1.39-1.65	56-67	1.44-1.67	60-77	1.56-1.86	53-80	1.48-1.78
Double alkali	37-40	1.30-1.35	41-44	1.33-1.44	50-62	1.38-1.62	55-58	1.50-1.61

without the fly ash layer, the presence of a fly ash layer beneath the sludge appeared to aid the dewatering process. The resultant process was nearly as effective as vacuum filtration. Because water retention in fly ash is relatively low, supernate water passes freely through the fly ash layer, creating air voids. It was postulated that, since the fly ash is contiguous with the sulfur-phase particles, surface tension forces between the fly ash particles and water are capable of overcoming the surface tension between the sulfur-phase particles and water. Thus, water is also removed from the sludge as it passes through the fly ash layer. The net consequence of this action is that more effective dewatering takes place.

4.3.2 Compressive and Load Bearing Strength

The structural characteristics of wet FGD sludge affects its use where land reclamation is desired. Therefore, the load-bearing strength of the sludge is an important factor in planning for acceptable disposal of FGD waste.

Unconfined compressive strengths of untreated wastes are low, and generally no specific values are reported because the material is usually too soft to measure.

Chemically treated sludges exhibit unconfined compressive strengths ranging from approximately 25 psi to 4500 psi in laboratory studies. However, commercial processes being used at power stations today produce values in the range of 25 to 400 psi (see Section 5.1.2).

Recently, load bearing strengths as a function of the solids content of wastes dewatered by settling, with underdraining such that surface drying occurs, have been reported (12) for a number of power plant FGD sludges, Figure 22. These results reinforce previous observations (13) that sludges may be dewatered to critical and narrow ranges of solids content, above which the load-bearing strengths increase rapidly to values well above the minimum for safe access of personnel and equipment. However, the critical concentration appears to be unique for each waste tested, and correlation with other physical or morphological characteristics was not apparent. Field evaluations (14) of underdrained ponds of lime and limestone sludges have shown these materials to be capable of supporting light construction equipment. Load bearing strengths in excess of 20 psi were reached.

The development of load bearing strength of various TVA Shawnee power plant lime sludge and fly ash mixtures as a function of the time the waste was allowed to dewater by settling, and with the water removed in an underdrained condition, is shown in Figure 23. The strength of settled wastes without draining is also illustrated. In the latter case, low bearing strengths are exhibited even after an extended settling period. As a result of underdrainage, high strengths were developed within several days. With limestone underdrained wastes, high load bearing strengths, e.g., 12 kg/cm^2,

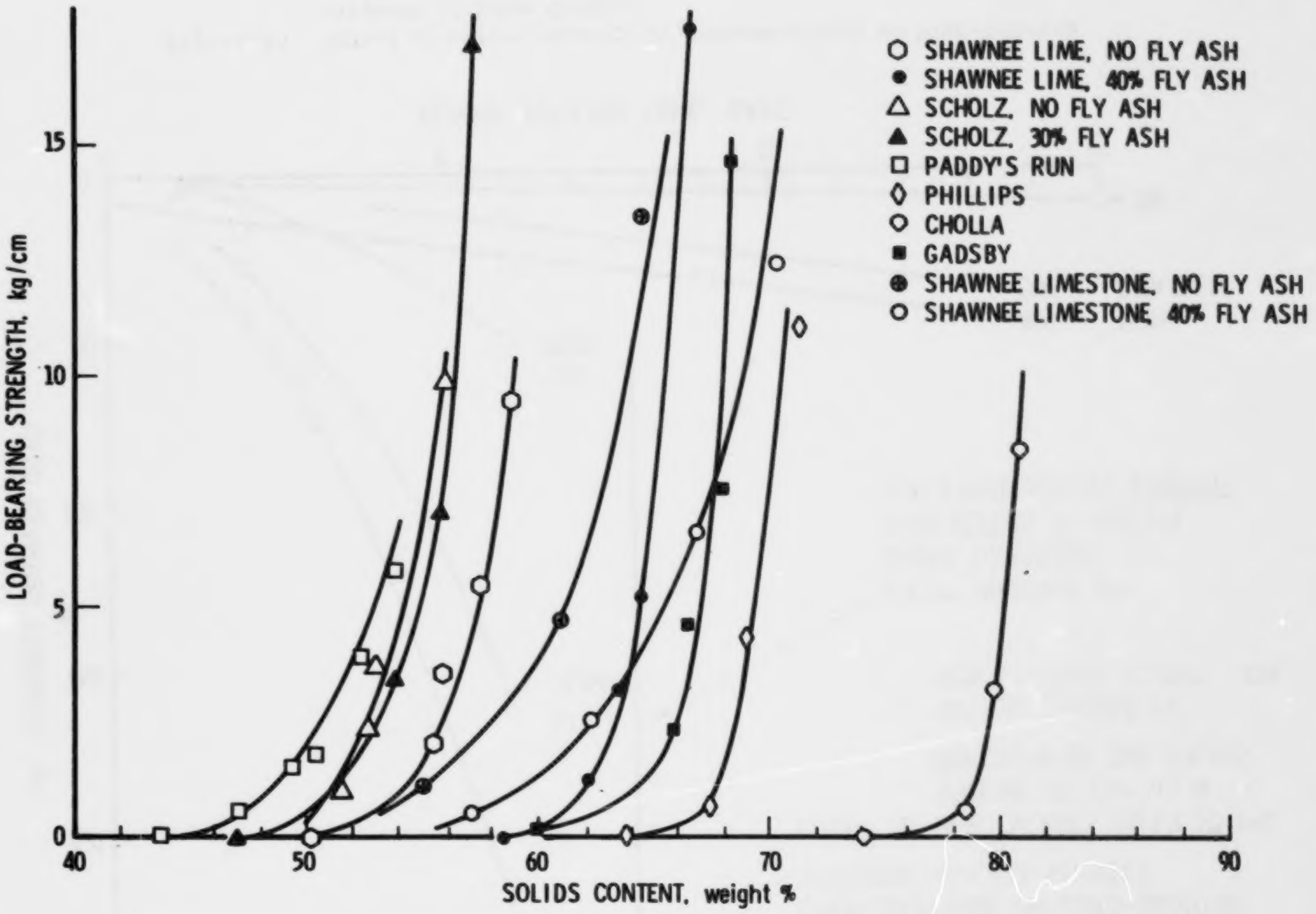

Figure 22. Compression strength of sludges and sludge/fly ash mixtures as a function of solids content.

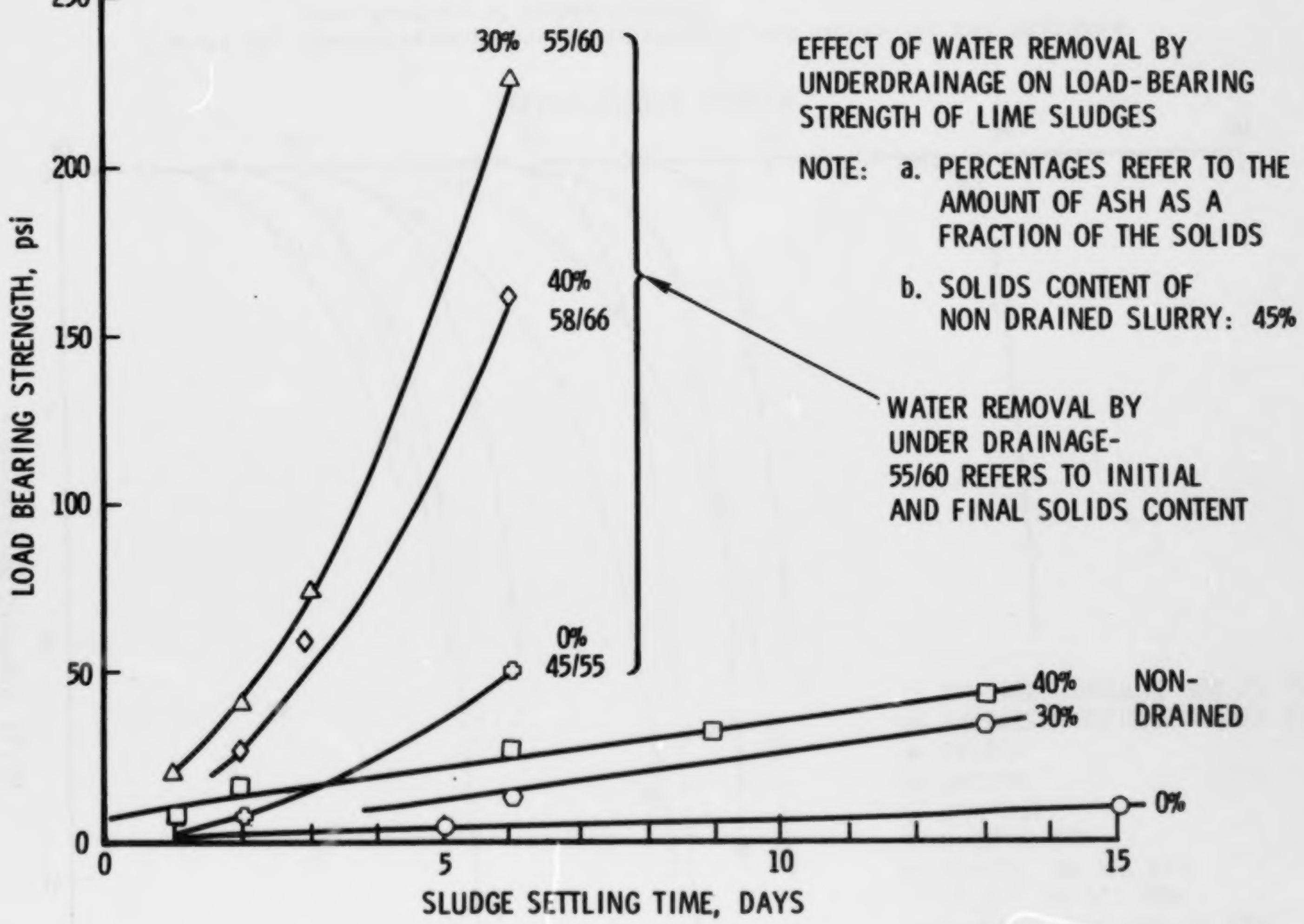

Figure 23. Effect of water removal by underdrainage on load-bearing strength of lime sludges.

were developed approximately 5 to 10 days after the same values were attained for lime wastes handled in a similar manner.

The effect of rewetting dewatered wastes with the equivalent of 1/2 inch of rainfall is also reported (12). A loss in load bearing strength was observed. However, its recovery, when allowed to drain, appeared to be comparable to the initial buildup.

4.3.3 Permeability

The pollution potential of sludge liquor into groundwaters is governed by the mobility of leaching waters, which is limited by the coefficient of permeability of the various media through which this leachate must pass.

Permeability of leaching waters through the waste defines an upper limit to the amount of leachate that enters the subsoil. The amount of liquid and the level of contamination of this liquid are jointly responsible for the pollution potential of any given waste disposal site.

The permeability coefficients of untreated wastes range from 2×10^{-4} to 5×10^{-5} cm/sec (10). The permeability coefficient of untreated sludges has been shown to be a function of the volume fraction of solids in the waste. These values are intermediate to typical values for silty sand and sandy clay, which are 10^{-4} cm/sec and 5×10^{-6} cm/sec, respectively. Values as low as 6×10^{-7} cm/sec have been reported for Louisville Gas and Electric carbide-lime untreated wastes. Sludge without fly ash has been found to have permeabilities about five times greater than the sludge with fly ash, with the solids fraction nearly identical for both materials. The difference is believed to be related to agglomeration of the fine sludge particles, which respond in a manner similar to coarser materials. When fly ash replaces the sludge particles, the solids fraction does not change, but the fly ash, having a broad particle size distribution, fills pore passages such that the rate of water passage through the waste is reduced.

Consolidation of untreated wastes under pressures of 30 to 100 psi reduces the void fraction and also reduces permeability coefficients by factors of from 2 to 5. The higher solid volume fraction, resulting from compaction or consolidation, and the decrease in permeability appear to be a function of the size of the sludge particles and the size and distribution of the fly ash particles. Consolidation of sludge at the base of a 40-foot-deep disposal site will decrease permeabilities to about 1×10^{-5} cm/sec as compared to 1×10^{-4} cm/sec at the surface. This value appears to represent the lower limit of untreated waste permeabilities expected in the field.

Chemical treatment tends to reduce permeability by less than a factor of 2 in some cases and several orders of magnitude in others (Section 5.1.2).

Weathering, such as freezing and thawing, has been reported to break up the monolithic structure of certain treated wastes (15). The permeability of several treated wastes that were mechanically fractured and powdered to simulate extensive weathering exhibited permeability values approximately the same as for untreated wastes. Fracturing (but not powdering) and compacting resulted in about one order of magnitude reduction of permeability relative to the powdered condition (11).

4.3.4 Viscosity

The viscosity of the liquid waste is a measure of its pumpability, which affects both the mode and cost of sludge transport.

The results of viscosity tests for ten sludges (12) show that easily pumpable mixtures (20 poise) range from a high solids content of 70 percent to a low solids content of 30 percent (Figure 24).

The waste materials produced in FGD systems contain finely divided particulate materials suspended in an aqueous medium and consist of three major phases having markedly different morphologies; calcium sulfite, calcium sulfate, and fly ash. It is both the particle size distributions and phase morphologies that are believed to influence the viscosity of the sludges.

Both calcium sulfate and calcium sulfite scrubber waste products tend to have particle sizes in the same range as fly ash; between 1 and 100 μm. However, fly ash is formed as spheres, while sulfite wastes are platey or rosettes, and sulfates are blocky in shape. Unreacted precipitated $CaCO_3$ from the limestone (or lime process) is usually present in the waste and contributes an additional shape parameter.

Whereas particle shape, particularly platey sulfite particles, has been suggested as the cause of the rheological nature of sludge, in the viscous-fluid behavior of these sludges it is not apparent that the sulfite phase plays a decisive role. On the other hand, the data clearly suggest that fly ash decreases the viscosity of a sludge and high pH (of a double-alkali system) increases it. Although particle shape, size, and distribution appear to influence viscosity behavior, the precise effect each may have is not clear from published results. In an instance with double-alkali sludge, the results tended to suggest that agglomeration of the fine particles, rather than their presence, also affected viscosity.

Considering the lack of characterization data, the importance of experimentally determined data for system design parameters is apparent.

4.3.5 Compaction

Questions may arise as to whether the compaction of FGD sludges may provide a means of increasing the mass of waste disposed of within a

CURVE	SLUDGE	FLY ASH, %
1	GM PARMA DOUBLE ALKALI	7.4
2	UPL GADSBY DOUBLE ALKALI	8.6
3	TVA SHAWNEE LIME	40.5
4	DLC PHILLIPS LIME	59.7
5	TVA SHAWNEE LIMESTONE	20.1
6	TVA SHAWNEE LIMESTONE	40.1
7	TVA SHAWNEE LIMESTONE	40.9
8	SCE MOHAVE LIMESTONE	3.0
9	APS CHOLLA LIMESTONE	58.7
10	TVA SHAWNEE LIME	0
11	TVA SHAWNEE LIMESTONE	0
12	LG&E PADDY'S RUN	12.4
13	GPC SCHOLZ SODA ASH	30
14	GPC SCHOLZ SODA ASH	0
15	TVA SHAWNEE LIME	40

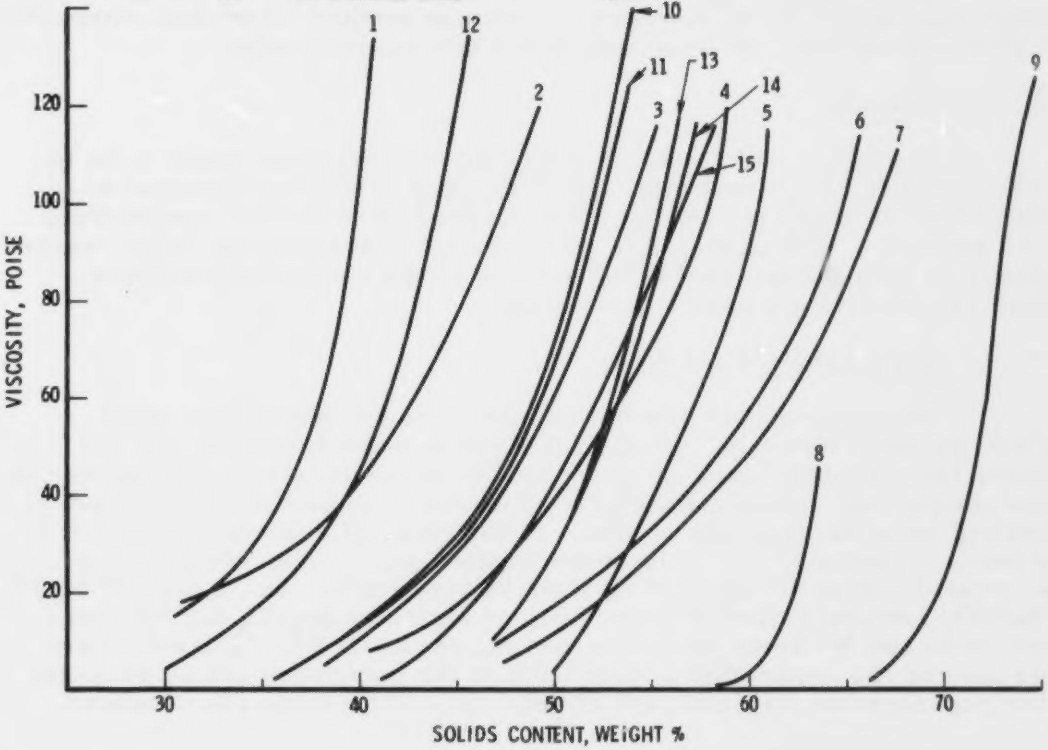

Figure 24. Viscosity of desulfurization sludges.

specified volume. Moreover, if compacted sludge behaves like fly ash, significantly reduced permeabilities and increased strength can be expected and these may increase the environmental acceptability of the sludge. The particle size distribution and crystalline morphology are the two most important parameters influencing the compactability of FGD sludges.

Compaction tests were reported (11) on lime, limestone, and double alkali sludges that had been dewatered to greater than 75 percent solids. Reduction in volume in the range of 7 to 15 percent was observed if pressures of 100 psi were maintained with lime and limestone wastes. Under comparable conditions, double-alkali wastes compacted 4 to 5 percent. However, upon release of the compressive load, permanent volume reductions of 1 to 4 percent were noted. In contrast, fly ash has been shown to compact from 7 to 20 percent.

These tests suggest that some benefit in untreated sludge volume reduction may be gained by compaction, but any method other than compaction by natural settling may not be practical for this purpose only.

4.3.6 Porosity

Porosity (void fraction) of untreated wastes was found to be in the range of 50 to 75 percent (16). Double-alkali waste data grouped at approximately 75 percent, and the lime and limestone wastes ranged from 50 to 65 percent. This property is an important characteristic of the waste because it defines the fraction of the volume of the sludge that contains occluded (retained) liquor after dewatering.

4.3.7 Regenerable Processes

The regenerable scrubbing processes do not produce solid scrubber wastes. However, these processes do not tolerate fly ash and, therefore, the scrubber must be preceded by an electrostatic precipitator to remove the fly ash, which generally is disposed of in ponds. Bottom ash is formed and must be disposed of also. A summary of ash properties (17) is given below. Inefficiencies in the regeneration processes, which may or may not be located within the generating plant battery limits, are losses of $MgSO_3$ and $NaHSO_3$ and are reflected as makeup of MgO and Na_2SO_3 for the magnesium oxide and Wellman-Lord processes, respectively. The solids and liquids leaving the separation step in each of the processes can be recycled into the regeneration step and, effectively, no solid wastes are produced.

The distribution of ash between the bottom ash and fly ash fractions is a function of the following:

a. Boiler type (firing method). The type of firing is perhaps the most important factor in determining ash distribution. Stoker-fired units emit the smallest proportion of fly ash. In cyclone units, 80 to 85 percent of the ash is melted and collected as slag. Pulverized coal units produce 60 to 85 percent fly ash and the remainder bottom ash.

b. Coal type (ash fusion temperature). Ashes with lower fusion temperatures tend to melt within the furnace and, therefore, to be collected as bottom ash.

c. Wet or dry bottom furnace. Wet bottom boilers are designed to produce and process a much larger proportion of bottom ash than are dry bottom boilers.

Fly ash makes up from 10 to 85 percent of the coal ash residue and occurs as spherical particles, usually ranging in diameter from 0.5 to 100 µm. Color varies from light tan to black, depending on the carbon content. A portion of fly ash is made up of very lightweight particles called cenospheres, which comprise up to 20 percent by volume of the fly ash. These cenospheres are spheres of silicate glass filled with nitrogen and carbon dioxide which range from 20 to 200 µm in diameter. They are "floaters," which create a suspended solids problem in pond disposal of ash. The chemical composition of cenospheres is very similar to that of fly ash.

The bottom ash, composed primarily of coarser, heavier particles than the fly ash, ranges from gray to black in color and is generally angular with a porous surface. If it is collected as a slag, these slag particles usually are black, angular, and have a glass-like appearance.

Petrographic analysis has shown that glass is the primary component of ash, constituting 50 to 90 percent of the total weight. Finer particles generally contain a higher proportion of the glass constituent than the coarser ones. Other components of the ash include magnetite, hematite, carbon, mullite, and quartz.

The chemical characteristics of ash depend largely on the geologic and geographic factors related to the coal deposit. The major constituents of ash — primarily silicon, aluminum, iron, and calcium — make up 95 to 99 percent of the total composition. Minor constituents, such as magnesium, titanium, sodium, potassium, sulfur, and phosphorus, comprise 0.5 to 3.5 percent. Ash also contains trace concentrations of from 20 to 50 elements, including, for example: antimony, arsenic, barium, beryllium, boron, copper, fluorine, lead, manganese, mercury, molybdenum, nickel, selenium, tellurium, thallium, tin, titanium, uranium, vanadium, and zinc.

Several studies have been made recently to determine the concentrations of these trace elements in the coal combustion residues. These studies were conducted on different sizes and types of systems with respect to megawatt output, collector configuration, boiler type, and operating conditions. Even the purposes of the studies differed. Yet, they were in fairly close agreement as to their findings on the distribution of elements among different fractions of the combustion residues.

Most of these studies agreed that elements were distributed into the fractions of coal combustion residue (bottom ash, fly ash, and vapors) according to definite patterns. The elements appeared to be divided into three main classes, as follows.

a. Elements that are approximately equally concentrated in the bottom ash and fly ash.

b. Elements that are enriched in the fly ash relative to their concentrations in the bottom ash.

c. Elements that are primarily discharged to the environment as gases.

Results from an analytical study conducted at the Tennesses Valley Authority (Table 30) partitioned elements into the above categories. The elements Cr, Cs, Na, Ni, U, and V were not placed into one of these three groups but were judged to exhibit behavior intermediate between the first two groups.

TABLE 30. PARTITION OF ELEMENTS BY THEIR TENDENCIES FOR DISTRIBUTION IN COAL COMBUSTION RESIDUES

Group I Elements Concentrated Approximately Equally in Bottom Ash and Fly Ash						
Al	Ce	Fe	La	Rb	Sm	Th
Ba	Co	Hf	Mg	Sc	Sr	Ti
Ca	Eu	K	Mn	Si	Ta	
Group II Elements Preferentially Concentrated in the Fly Ash						
		As	Ga	Sb		
		Cd	Mo	S		
		Cu	Pb	Zn		
Group III Elements Tending to be Discharged to Atmosphere as Vapors						
		Hg	Cl			
			Br			

Results from a study of three Northern Great Plains plants showed that As, Sb, Se, V, Pb, Mo, Ni, B, Zn, Cd, Cr, Cu, Co, U, Ag, S, Hg, Cl, and F were enriched in the fly ash plus flue gas samples, with S, Hg, and Cl appearing to be emitted from the plant as gaseous species. Thus, in examining just one category, i.e., elements preferentially concentrated in the fly ash, the conclusions of several studies are generally consistent. This agreement of results is notable, considering the differences in the furnace types, coaltypes, and sampling and analytical procedures.

Elements named by one or more studies as primarily emitted to the atmosphere in the vaporous phase include Cl, F, Br, Hg, S, and Se. Most sulfur is emitted as SO_x and the halogens as hydrogen halides, all of which are scrubbed in an alkaline SO_x scrubber (CaO, $CaCO_3$, or $NaSO_3$)

Obtaining representative samples for coal and ash characterization is often difficult because of variations in coals and complications in stack sampling, particularly for fine particulate. Comparisons in characterization also are impeded by differences in the analytical methods chosen.

4.4 Potential Environmental Impacts

The environmental impact of flue gas desulfurization (FGD) sludge disposal depends not only on the properties of the sludge but also on the site's climatological and hydrological conditions and its geographic location. Therefore, a sludge's environmental impact may be determined on the basis of its anticipated behavior under various alternative methods of disposal.

The following sections discuss the expected impact of FGD sludges on the environment with respect to the range of properties referenced in this study. It is assumed that the range of properties summarized are representative of the sludges that are being and will be produced. In the data base available for this study, an attempt was made to separate the effects of eastern and western coals; lime, limestone, and double-alkali systems; sludges with and without fly ash; and systems operating at both high and low pH. Although results for every combination of variables were not available, it is believed that the following discussions will be applicable to a major portion of the sludges that will require disposal.

To evaluate the environmental impact of alternative disposal techniques for FGD wastes, it is necessary to assess various routes by which chemical pollutants may enter the environment from a disposal site and to determine the relative mobility of the various chemical species with respect to their availability and accessibility to water supplies. Thus, in addition to chemical characterization of FGD sludges, the physical properties that control the mobility and manner that the pollutants may enter the aquatic environment must be considered.

4.4.1 Water Pollution

The disposal of FGD wastes make possible several alternative routes by which chemical constituents in the desulfurization wastes may enter and pollute surface and underground waters. Untreated waste is generally disposed of in an impoundment as a mixture of solids and occluded liquor. Pollutant transfer may take place as a result of rainwater displacing liquors occluded in the sludge and containing chemical constituents, and leaching constituents out of the sludge itself, or by rainwater running off the sludge surface and dissolving and entraining chemical constituents. Water may be polluted by leachate seeping through the soil below the disposal site into groundwater or uncollected runoff seeping into the soil surrounding the disposal site and then into groundwater, or the runoff draining directly into surface streams and rivers.

4.4.1.1 Pollution by Runoff

The potential environmental pollution by rainwater runoff from the surface of FGD sludges exists through the action of surface leaching of chemical constituents and from erosion of particulates from the surface. Subsequently it can affect either surface waters, if the runoff flows directly into streams, or groundwater, if the runoff is allowed to percolate through adjacent land. This applies to sludges that are disposed of as a landfill, either above or below grade. At this time, only chemically treated sludges are being disposed of operationally as described above. When treated sludge is disposed of by this method and the site is managed to facilitate landfill operations such as placement and compaction, rainwater is not allowed to stand on the surface, and therefore runs off. The potential environmental effects of this runoff would be of concern.

The environmental concern for these sites results from the fact that freshly treated sludges could produce relatively high concentrations of suspended and dissolved solids in the runoff compared to those from a cured material. Since freshly treated material is added to the site continuously, the concern for the quality of the runoff would exist throughout the development period of the landfill. Currently, a runoff collection ditch leading to a siltation pond is used to prevent pollution from suspended solids; the collection of water from a major portion of the landfill area allows for dilution of excessive dissolved solids from local areas of the site containing freshly treated sludge. Freeze-thaw cycling may periodically create runoff problems by exposing new surface areas to rainwater; therefore, a compacted overburden of soil is desirable for completed portions of the landfill.

These observations represent only a limited examination of runoff conditions. Current programs by private firms and the EPA are expected to produce a better understanding of these potential problems.

4.4.1.2 Pollution of Groundwater

A potential for the pollution of groundwater exists as a consequence of the action of rainwater leaching through untreated waste in a disposal basin. For untreated sludge, this pollution potential can exist because the disposal basin is generally designed to impound sludge liquors and rainwater. Water percolates through sludge whenever free standing water collects on its surface. The amount of leachate that percolates through the sludge depends upon the permeability of the sludge, the permeability of the basic subsoil, and the quantity of water entering the basin either by rainfall or other sources. The quality of the leachate depends on the availability of chemical species to the percolating waters.

Untreated sludge normally contains occluded liquor from the scrubbing process in an amount representing 35 to 80 percent by weight of the total sludge, depending upon the extent of dewatering. Most of this occluded liquor is flushed from the sludge by the first three to five pore volume displacements (PVD) of percolating water (see Section 4.2.4). Thereafter, the leachate attains a nearly constant total dissolved solids (TDS) content of 2000 mg/ℓ, which primarily represents the solubility of calcium sulfate. Initial leachate content is as high as the soluble chemical content of the sludge liquor and is dependent upon the type of FGD system.[1]

The rate at which water passes through untreated FGD wastes is approximately 10^{-4} cm/sec, equivalent to silty sand soils. A method of quantifying the pollutant potential is to calculate the mass loading (mass per unit area) of constituents into the subsoil.

Calculations were reported (11) for an untreated FGD waste containing 6000 mg/ℓ dissolved solids in the occluded mother liquor, and the impact of disposal by alternative techniques was considered. Chemically treated wastes are also presented to illustrate the effects of this alternative. The rate of leachate seepage through the untreated sludge would be 10^{-4} cm/sec, and 10^{-5} cm/sec for treated sludge. In these examples, the waste was assumed to be placed to a depth of 30 feet during a 5-year fill period.

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[1] In comparison, leachate through treated FGD waste has an initial TDS content of nominally one-half that of untreated waste, and after five PVD it attains a level of one-half to one-fourth that of the leachate from untreated wastes (see Section 5.1.2).

The results of this assessment are presented in Figure 25 for cases described in Table 31. Cases 1 and 2 represent the ponding technique of disposal in which the site is continuously inundated with water, which may include runoff from surrounding areas. Case 1 is for untreated FGD waste, and Case 2 is for treated waste. Cases 3 and 4 represent pond disposal of untreated and treated waste, respectively, in which rainfall is trapped in the impoundment, and the disposal site is retired by grading and landscaping. In these cases, the amount of water recharged to the subsoil represents a normal recharge for indigenous soil. Case 5 is the condition in which treated FGD waste is disposed of in a landfill managed such that 1 inch of the assumed normal available recharge of 10 inches is allowed to penetrate the waste because runoff from the surface has been maximized. Figure 26 illustrates the mass loading of the total dissolved solids (TDS) that is expected to reach the disposal site subsoil per year as a function of time. Each curve also indicates the point in time at which the flushing action of the leachate reaches five PVD; i. e., when the occluded water is flushed out and solubility becomes important.

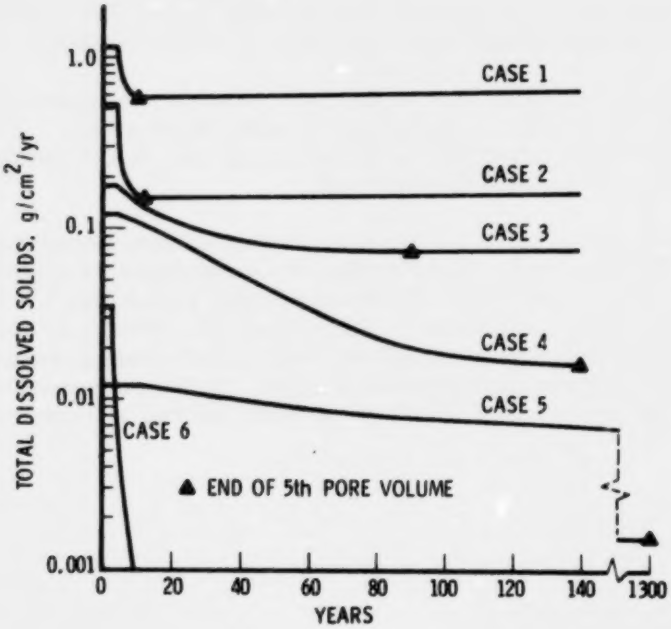

Figure 25. Mass loading of TDS to subsoil for various disposal modes of treated and untreated FGD wastes

TABLE 31. INPUT DATA FOR STUDY CASES

Case	Disposal Method	Surface Water	FGC Waste, 5-Year Fill			
			Waste Condition	Depth ft	Permeability, cm/sec[b]	Fractional Pore Volume
1	Lake[a]	Constant supernate	Untreated	30	10^{-4}	0.67
2	Lake[a]	Constant supernate	Treated	30	10^{-5}	0.67
3	Pond	10 in/yr recharge	Untreated	30	10^{-4}	0.67
4	Pond	10 in/yr recharge	Treated	30	10^{-5}	0.67
5	Landfill	1 in/yr recharge	Treated	30	10^{-5}	0.67

[a] Assumed maximum hydraulic head of 6 ft during filling, including depth of wastes; 1-ft constant water cover thereafter.

[b] For all cases, subsoil permeability = 10^{-5} cm/sec.

This evaluation shows that the mass loading of pollutants to the subsoil from an untreated site which is continuously covered with water can be reduced by one order of magnitude if runoff is prevented from entering the site (only rainfall enters), and several orders if wastes are treated and the site is managed to shed water. Additionally, the significance of disposal site management as a means of preventing chemical pollution to the environment is illustrated. For example, chemical treatment reduces solubility by one-half or more. Also, with the permeability reduced by at least one order of magnitude, runoff from the site is increased, thereby reducing the recharge rate by a factor of 10.

The implications of chemical treatment of wastes in conjunction with other techniques of FGD disposal are discussed in Section 5. 1.

4.4.1.3 Impact Assessment

In summary, it has been determined that untreated waste chemical properties tend to be a function of the coal and scrubbing process variables. Furthermore, the waste characteristics are also a function of the treatment process itself. Prime factors to be considered in evaluating the environmental impacts of disposing FGD wastes are provided below. Untreated waste characteristics and impacts are discussed in conjunction with chemically treated wastes to provide a frame of reference.

a. Strength. Because of the rheological nature and structural characteristics of untreated wastes, personnel and equipment safety cannot be ensured unless specific measures are taken, such as pond underdraining (see Section 4.3.2). Treated material, depending on the chemical treatment process and the solids content, can be expected to achieve strengths in excess of those considered minimal for supporting personnel and equipment and, in some cases, building structures. The long-range effect of weathering, i.e., wet-dry and freeze-thaw cycling, is yet to be defined.

b. Permeability. The permeability coefficient of untreated material is approximately 10^{-4} to 10^{-5} cm/sec. Chemical treatment tends to reduce these values over a broad range, from negligible to several orders of magnitude, depending on the process selected. The long-range effect of weathering on permeability of wastes is yet to be determined.

c. Leachate Concentration. Laboratory and field leaching data have shown that leachate concentrations of major species in the leachate from chemically treated materials are about 25 to 50 percent of the concentrations of major species in untreated materials.

d. Leachate Mass Release. The mass release of major constituents into the soil from chemically treated materials is reduced as a result of lower permeability of the treated wastes, a reduction of the solubility of major pollutant constituents, and elimination of hydraulic head via runoff. The treatment process and mode of disposal, i. e., pond, landfill, or lake, determine the mass loading of pollutants into the soil, which can amount to a reduction of one to many orders of magnitude when compared to untreated materials.

4.4.2 Ability to Support Vegetation

There is a general lack of published information on the ability of FGD waste materials to support vegetation. This may be expected, however, because the anticipated modes of reclaiming disposal sites do not consider their use in such a manner, i. e., without a soil cover.

Insight on the consequences of effect of FGD waste constituents on vegetation, however, can be obtained from a number of sources. Use of gypsum as a soil amendment is well known. Also, the use of fly ash is being studied extensively (18, 19) and the effects of the plant uptake of various trace elements from the ash is being assessed.

EPA and the State of Illinois (16) have funded programs to use FGD wastes in the production of fertilizer. Emphasis to date has been on processing, with plant uptake experiments to follow. However, preliminary small-field-plot application of FGD-produced fertilizer on rye grass by TVA was encouraging and formed a basis for pursuing pilot plant production studies under EPA funding.

SECTION V

ASSESSMENT OF WASTE DISPOSAL AND UTILIZATION TECHNOLOGY

5.1 ENVIRONMENTAL IMPACTS OF DISPOSAL PROCESSES AND PRACTICES

It has been determined that the chemical and morphological properties of untreated waste tend to be a function of the coal and, more importantly, a function of the scrubbing process variables. The morphology tends to establish the settling and dewatering characteristics of a particular slurry. Detailed characterization of scrubber solids as a function of scrubber operating parameters on the properties and work in that area is being conducted (10) under EPA funding. Furthermore, chemically treated waste characteristics are also dependent on the treatment process itself. Prime factors to be considered in the disposal of FGD wastes are as follows.

a. Structural Strength. Because of the rheological and structural characteristics of untreated wastes, personnel and equipment safety cannot be ensured. Treated material, depending on the treatment process and the solids content, can be expected to achieve strengths in excess of those considered minimal for supporting personnel and equipment and, in some cases, building structures. The long-range effect of weathering on strength, i.e., wet-dry and freeze-thaw cycling, is yet to be defined.

b. Permeability. Permeability coefficients of untreated materials range from 2×10^{-4} to 5×10^{-5} cm/sec. Chemical treatment tends to lower these values over a broad range (from negligible to several orders of magnitude) depending on the process, chemical additive, and the solid content of the treated material. The long-range effect of weathering on permeability is yet to be determined.

c. Leachate Concentration. Laboratory and field leaching data show that leachate concentrations of major species in the leachate from fixed materials are about 25 to 50 percent of the concentrations of major species in untreated materials.

d. Leachate Mass Release. The mass release of major constituents into the soil from chemically fixed materials is reduced as a result of lower permeability of the treated wastes, a reduction of the solubility of major pollutant constituents, and, in some cases, a minimization of seepage by controlled runoff. The treatment process and mode of disposal, i.e., landfill or lake, determine the mass loading of pollutants into the soil, which can amount to reductions of one to several orders of magnitude when compared to untreated materials.

e. Soil Attenuation Effects. The extent that trace elements and other chemical constituents of FGD wastes may be attenuated in soils or their mobility to migrate through soils at land disposal sites is being studied by the U.S. Army under EPA sponsorship (10). Soil and waste characterization tests are complete. However, work has not progressed to the point where quantitative information on the migration and attenuation of FGD waste constituents has been determined.

f. Liner Evaluation. An experimental program to determine the compatibility and effectiveness of 18 liner materials with FGD wastes, liquors, and leachates is under way. Material screening tests have been conducted. Materials have been selected, and testing has begun in test cells. Since the exposure of materials to various wastes has been limited and definitive information is not available at present, a 2-yr exposure is planned. The economics of FGD disposal by ponding will also be assessed.

g. Waste Dewatering Methods. Studies are being conducted to determine dewatering characteristics of FGD wastes and to define areas where improvements can be made in dewatering equipment or techniques. Since the program is in its early stages, quantitative information is not available. However, results from this work are expected to be used in assessing benefits derived from a reduction of: dewatering equipment size, waste volume handled, disposal acreage, and chemical additives.

h. Field Disposal Evaluation. A project to evaluate and monitor the field-site disposal in indigenous soil impoundments of untreated and treated FGD wastes has been under way for over 3 yr at the TVA Shawnee power plant site (14). Its purpose is to determine the effects of several scrubbing operations, waste treatment methods, disposal techniques, soil interactions, and field operation procedures. Test samples of treated and untreated wastes, groundwater, surface water, leachate, and soil cores are being analyzed in order to evaluate the environmental acceptability of current disposal technology.

The analysis of groundwater shows no indications of increases in concentration levels attributable to the presence of any of the ponds.

The total dissolved solids (TDS) and the concentration of major constituents in the supernates of the untreated ponds decreased with time from initial values corresponding to the values measured in the input liquor. After the initial decrease, fluctuations were observed in which concentrations increased during dry weather and decreased again when increased rainfall caused additional dilution. For the treated ponds the concentrations of major constituents and TDS in the supernate varied as a function of dry and wet weather during the monitoring period and did not exceed values of one-half to two-thirds of the corresponding concentration of the constituents in the input liquor.

Generally, the TDS, SO_4, Ca, and Cl in the leachate from untreated ponds reached the input concentration and decreased steadily thereafter to a level approximately one-half the concentration of the input liquor. Minor constituents whose concentrations span a range of six orders of magnitude were relatively constant over the period monitored. The analyses of leachate from the ponds containing treated sludge show data trends similar to the untreated ponds; however, TDS levels consistently remain at a level approximately one-half of the levels found in the input liquor. Six minor constituents remained at relatively constant levels throughout the monitoring period, with the exception of the boron level in one treated site which increased steadily to a level approaching that of the input liquor.

An evaluation of the environmental effects of settling and the structural characteristics of disposing of untreated lime wastes in underdrained field impoundments at the Shawnee site were initiated in late 1976. Monitoring of underdrained limestone and gypsum evaluation sites started in early 1977.

Other field evaluations of FGD waste test impoundments and full scale disposal sites are in early stages of implementation by Louisville Gas and Electric and the U.S. Army Corps of Engineers (10).

It is apparent that each disposal site and the material placed in it have individual characteristics different from most others. These include waste material properties, weather, topography, soil characteristics, and nearby stream quality and flow characteristics. Therefore, the disposal method chosen for any site will generally be selected on site-specific conditions. Because of this, the establishment of a single criterion for all cases may be overly conservative in one location and not stringent enough in another.

Various disposal and waste conversion processes and practices are capable of minimizing environmental impacts on aquifers and groundwaters. These are discussed in subsequent sections and include:

a. Ponding of untreated waste, with various alternatives

b. Chemical treatment of waste, and landfill disposal

c. Mine disposal of untreated waste

d. Ocean disposal of treated waste

Processes that produce useable products that minimize or reduce the disposal of wastes include:

a. Conversion of gypsum for wallboard and other uses

b. Production of sulfur or sulfuric acid

c. Use as a synthetic aggregate

5.1.1 Ponding

The method that represents the least deviation from state-of-the-art fly ash disposal is direct ponding of untreated wastes into a disposal basin. The environmental impact of pond disposal is strongly dependent upon the ability (a) to contain the components of a sludge so as to prevent environmental pollution, and (b) to retire the disposal site in a manner that does not create a safety hazard or nuisance in subsequent land use. For pond disposal, the environment can be protected from chemical pollution, principally from leachate contamination of groundwater, by lining the pond basin with elastomeric material or impermeable clay. Some natural clay deposits have sufficiently low permeabilities (effectively impermeable) that sludge disposal can be safely contained in a natural basin. If an impermeable base is not used, it is expected that not all trace elements will be attenuated by the subsoil. Additionally, soils do not significantly attenuate chloride or sulfate ions.

The disposal site may be reclaimed either by maintaining the pond as a lake or by allowing the sludge to dry and covering it with soil overburden. To maintain the retired disposal basin as a lake, it is necessary to provide a balance between water loss and water input. The water loss will be by evaporation, and, when no liner is used or when a breach is developed in the liner, loss also occurs by percolation through the subsoil. Precipitation in excess of loss requires a means for eliminating excess water, which must be monitored.

If a pond is reclaimed by air-drying the sludge and covering it with a soil overburden, certain restrictions may limit reuse of the land. Proper contouring to control rainfall runoff to minimize percolation of water through the overburden will be necessary to avoid resaturating the sludge. Therefore, using site management, it may be possible to dispose of untreated FGD sludge by ponding in an environmentally acceptable manner.

Another ponding alternative to dispose of untreated FGD waste is by including provision for pond underdrainage. This method retains the advantage of transferring the sludge to the disposal site by liquid transfer. The leachate from the base of the sludge is returned to the scrubber. The advantages of this method may be economic and environmental. By eliminating a supernate head above the sludge most of the time, and minimizing it for short periods after rainfalls, percolation of sludge leachate into the subsoil can be avoided during the active fill period. Tests have shown drained sludge to have structural qualities adequate to support lightweight construction equipment. To retire the disposal site, only several days of air drying after a rainfall are needed before covering with topsoil. Subsequent cover contouring is necessary for the reasons discussed in ponding, but the underdrainage system provides a means of sampling and elimination of leachate if required to prevent groundwater contamination. Significant economic advantages of this method could be its relative reclamation potential and the elimination of the requirement for a disposal basin liner. Evaluation of this technique is continuing in EPA programs (12, 14).

On the basis of the potentially favorable environmental and economic benefits discussed above, cost estimates for two ponding methods of disposing of FGD wastes are discussed in Section 5.2.2.1, i.e., use of (a) an elastomeric liner or an added clay liner, and (b) indigenous clay (impervious) soil.

5.1.2 Chemical Treatment

FGD sludge may be treated chemically by several processes, and can typically be used in landfill applications. Chemical treatments such as those offered by IU Conversion Systems, Inc. (IUCS), Dravo, Inc., and the Chemfix process vary in terms of the chemical additives used to physically stabilize the sludge, reduce its permeability, and also reduce the release of chemical constituents into water permeating through the treated material.

Currently, FGD sludge from seven sites using lime-limestone scrubbing processes totalling 2690 MW are being chemically treated (34). Full-scale sludge treatment at these locations was started in 1972 with one 200-MW site. In 1976, an additional unit of 825 MW started up. The remainder began treatment in 1977. Four additional sites totalling 2773 MW are expected to initiate chemical treatment of FGD wastes in the near future. In addition, full-scale evaluation work has been conducted since 1972 at a number of locations including Duquesne's El Rama and Phillips Stations, and Southern California Edison Mohave Nos. 1 and 2, as well as prototype evaluations at the Tennessee Valley Authority (TVA) Shawneee site (16, 21).

An evaluation of these three processes (21) indicates that the soluble salt content in the leachate from treated sludges is typically about one-half that of the untreated sludge. Additionally, the permeability of the treated sludge appears to be at least one order of magnitude less than that of the untreated sludge. Therefore, the dissolved salts that may be leached from chemically treated sludge and available to the environment are considerably less in concentration and mass than from untreated sludge.

For every process examined, the structural stability of the treated sludge exceeded that of the untreated sludge. The treated sludge texture ranged from soil-like to concrete-like and developed strength equal to or in excess of natural soils. Restrictions on subsequent land use will depend upon local conditions and the long-time stability of the treated sludge. Laboratory data have not been developed by any source from which it would be possible to predict the time-dependent stability of treated sludge.

Chemically treated sludges can be used as landfill in submerged and above-grade conditions. In the submerged condition, the sludge may serve as a lake bottom; however, the constant hydraulic head requires a continuing monitoring of local streams to detect any possible leakage from the site. In an above-grade condition, the material can be placed and compacted such that rainwater does not penetrate the surface and a leachate is not produced. However, provisions are generally required to manage runoff from these sites. The potential environmental impact of treated sludge is less than that of untreated sludge under most disposal methods, although the added assurance afforded by the chemical process increases the cost of disposal.

The cost effectiveness of chemical treatment must be evaluated in the context of specific land use limitations and disposal site restrictions that exist as unique conditions at each power plant facility. Cost estimates for treatment by a typical chemical process and with landfill disposal are provided in Section 5.2.2.2.

5.1.3 Mine Disposal

In a study (22) assessing the technical, environmental, and economic factors associated with mine disposal of FGD wastes, four general categories of mines were examined: active surface-area coal mines, active underground coal mines, inactive or mined-out portions of lead or zinc mines, and inactive or mined-out portions of active underground limestone mines. In addition to the environmental impacts, each category was reviewed with regard to: the alternatives for placement, the physical properties of FGD wastes that would be suitable, the operational impacts, the capacities, and the availability and accessibility (via transportation systems) for FGD waste disposal. As a result of this review, the following mines were determined most promising:

a. Active Interior Region surface-area coal mines

b. Active Eastern and Interior Region room-and-pillar underground coal mines

In general, Interior region surface-area coal mines appear to be more promising than western (Rocky Mountain and Pacific Coast) surface-area coal mines. However, surface-area mines both in the Interior and the West were considered much more promising than eastern surface contour mines, because of the latter's relatively low capacity for FGD wastes and, in many cases, the difficulty for waste placement in contour mines.

Individual Interior region surface-area mines have substantial capacity for receiving FGD wastes, and disposal is considered technically feasible within existing mine operations. The wastes must be dewatered to the extent necessary for landfill operations, so that they can be dumped into a mined-out strip (which can be adjacent to one being mined) and covered with overburden. Placing FGD waste in the mine void assists in returning the terrain to its original elevation.

The principal environmental impact anticipated from this disposal method is an increase in total dissolved solids (TDS) in waters that are recharged by leachate from the disposal site. This impact may be lessened by placing part of the overburden in the mined-out strip prior to placing the FGD waste, thereby elevating the waste above the groundwater table. In addition, dilution to acceptable TDS levels can be encouraged by maintaining a suitable distance between the disposal site and the stream, or by ensuring that the receiving streams have a sufficiently high flowrate.

Based on the potential environmental acceptability of mine disposal discussed above, cost estimates for disposing of untreated FGD wastes in active surface and underground mines are discussed in 5.2.2.3.

5.1.4 Ocean Disposal

In a study assessing the ocean disposal of FGD wastes (22) various methods of transportation and disposal were examined, including surface craft (e.g., bottom-dump barge and slurry dispersion) and pipeline (outfall). Various chemical and physical forms of the FGD wastes were also considered, i.e., sulfite-rich wastes, sulfate-rich wastes, and chemically treated wastes in both "soil-like" and "brick-like" forms. Both continental shelf and deep ocean disposal of the wastes were examined.

Until more definitive data are available, disposal of sulfite-rich FGD wastes on the Continental Shelf or in the deep ocean was not considered to be advisable. In addition, the study concluded that all soil-like FGD wastes, whether sulfite or sulfate and treated or untreated, should not be disposed of by quick-dumping surface craft or pipeline (outfall) on the Continental Shelf. Several options using surface craft appeared promising:

a. Dispersed disposal of sulfate-rich FGD wastes on the Continental Shelf

b. Concentrated disposal of chemically treated brick-like FGD wastes on the Continental Shelf

c. Dispersed disposal of sulfate-rich FGD wastes in the deep ocean

d. Concentrated disposal of both sulfate-rich and chemically treated FGD wastes in the deep ocean

However, the environmental effects of layering the bottom with wastes described in a, c, and d above have yet to be defined. In addition, their environmental effect while traveling down the water column is also unknown.

A more promising method is considered to be item b above. This is based on the favorable characteristics of treated materials in laboratory leaching and permeability tests. Long-term effects on the volumetric and structural integrity of the material as affected by submergence in sea water are unknown.

Experiments sponsored by the New York State Energy Research and Development Authority (NYSERDA) are evaluating the physical, chemical, and biologic characteristics of blocks of chemically treated scrubber wastes (23). Laboratory experiments have been encouraging, and a 10 ft^3 reef constructed of blocks of chemically treated wastes will be placed in Long Island Sound. The physical stability of the reef and its effects on the local marine biology will be studied, and other related assessments will be made.

Based on the results of the various studies showing the potential feasibility for ocean disposal, cost estimates for disposing of chemically treated FGD wastes on the eastern seaboard Continental Shelf are provided in Section 5.2.2.4.

5.1.5 Conversion to Gypsum

Experiments on the forced oxidation of sulfite sludges to form gypsum for potential use in wallboard were conducted by EPA at Research Triangle Park and by Southern Services at Plant Scholz using the Chiyoda process. Wallboard has been fabricated using a 50/50 blend of Chiyoda gypsum and the natural material (24). However, evaluations of the properties of FGD gypsum specifically related to manufacturing wallboard and its application were not available.

Wallboard produced from SO_2 scrubbing processes has had extensive application in Japan, and properties relative to this material have been reported (25). However, the material has been produced from scrubbing of flue gases from oil-fired boilers, and the relationship between SO_2 concentration in the flue gas and scrubber operating conditions on the properties of the gypsum from the oil-fired units in Japan and from the coal-fired applications in the U.S. are unknown. Estimates for the cost increment required to adapt to new scrubber systems during construction have been made (24) and reported in Section 5.2.3.1. Since no data were available, in that analysis it was assumed that the resultant properties of the ash-free gypsum would be satisfactory for wallboard use.

5.1.6 Conversion of Sulfuric Acid or Sulfur

Regenerable FGD processes are, in reality, chemical processing plants which, if applied to power plants, add new dimensions to the plant operating and marketing programs.

Both the magnesium oxide and Wellman-Lord processes require a complex plant to regenerate the SO_2 from the absorbent, and to reduce the SO_2 to sulfur or convert it to sulfuric acid. The Wellman-Lord process uses an evaporator to regenerate the absorbent and form SO_2. It then requires methane and H_2S in the plant devoted to the reduction of SO_2 to sulfur. The magnesium oxide process requires a fluidized bed reactor and coke to regenerate the SO_2, which then must be processed further to form the sulfur or sulfuric acid by-products.

Formidable problems identified with regenerable processes (26) include: (a) lack of good material balance data from pilot plants, the absorbents are expensive, and the economics are significantly affected; (b) hazards of employing a toxic reductant like H_2S around power plants which have not been subject to such practices: and (c) the availability and generation of H_2S. This includes process technology problems that have not been demonstrated; such as a high-temperature catalytic generation process, lack of experimental data on the catalyst life and durability, and reactor corrosion.

A brief discussion of the technology based on recent surveys and operational status of existing plants is provided below.

5.1.6.1 Magnesium Oxide

Three MgO plants have been tested (Table 32). Two have shut down completely as SO_2 scrubbers, and a third is in a particulate scrubber mode only since February 1976 because of the difficulty in locating a chemical plant to process the spent absorbent (it is scheduled to start up again as an SO_2 scrubber in mid-1977). The two shut-down plants experienced the same problem (8). In general, it is considered (26), that the scrubbing process

TABLE 32. STATUS OF MAGNESIUM-OXIDE SCRUBBING PLANTS

Installation Site, Size, and Fuel	Status
Boston Edison, Mystic No. 6, 150 MW, oil, 2.5% sulfur	Start-up 4/72, shutdown since 6/74
Potomac Electric, Dickerson No. 3, 95 MW, coal, 2% sulfur	Start-up 9/73, shutdown since 8/75
Philadelphia Electric, Eddystone No. 1, 120 MW, coal, 2.5% sulfur	Start-up 9/75, shutdown SO_2 scrubber 2/76[a]

[a] Shutdown—acid plant regeneration facility ceased operations. Another facility located. Expect to resume SO_2 scrubbing and $MgSO_3$ regeneration in mid-1977.

has been demonstrated; experiencing the usual corrosion and mechanical problems typical of placing a scrubber system into operation (8). The major problem has been in the accessibility of a $MgSO_3$ regenerating plant. To operate effectively, an on-site or central regenerating plant servicing nearby scrubber operations may be needed.

5.1.6.2 Wellman-Lord

The Wellman-Lord system has been successfully operated on tail gas from Claus and H_2SO_4 plants and an oil-fired flue gas, but not coal-fired boiler flue gas (26).

A retrofit system is scheduled to go into operation in mid-1977 on the 115-MW boiler at the Dean Mitchell Station of Northern Indiana Public Service burning 3- to 3.5-percent sulfur coal. Elemental sulfur (99.5 percent purity) is expected.

Public Service of New Mexico is installing Wellman-Lord systems at its San Juan No. 1 and 2 stations, which generate in excess of 700 MW. Start-up is expected in November 1977. Low sulfur (0.8 percent) coal will be used in the boilers.

5.1.7 Use as a Synthetic Aggregate

Chemically treated waste has been used in limited instances as synthetic aggregate for road base materials.

Poz-o-tec® is a process that is used by IU Conversion Systems Inc., to chemically treat wastes capable of being processed as synthetic aggregate. Its application has been used primarily in road base construction materials, with some application as dikes and liner material at a disposal site (27) in the greater Pittsburgh area and in Mohave County, Arizona. It has also been used to reclaim land in a housing tract. Ross Township, Pennsylvania, has approved a specification for its use in road base construction.

The economics of its use appear to be highly site specific relative to its source and end use; however, no cost data have been published.

5.2 ECONOMIC EVALUATION OF DISPOSAL PROCESSES AND PRACTICES

Capital and operating cost estimates for six FGD waste disposal methods, and one process producing saleable gypsum, were compiled from several sources (12, 21, 22, 28, 29, 30).

The methods considered were: (a) pond disposal of untreated waste, using a flexible liner and clay soil indigenous to the site, (b) chemical treatment of the wastes, with landfill disposal, (c) coal mine disposal of untreated waste, (d) ocean disposal of chemically treated wastes, and (e) production of oxidized sulfite sludge (gypsum) as a commercial product. Since cost data obtained from the references noted above had been prepared for differing plant sizes and based on various time periods, the estimates were adjusted to reflect July 1977 dollars and, where applicable, to reflect a range of power plant ratings from 25 to 1000 MW. Also, the cost of land considered for disposal purposes was uniformly estimated to be $5000 per acre. Ninety percent SO_2 removal efficiency was the basis for these cases.

5.2.1 Economics Related to Power Plant Operating Conditions

The adjustments in disposal costs resulting from variations in power plant unit size were made using data developed by TVA for advanced desulfurization processes (28). After examining both capital and operating cost data for new power station equipment, factors were calculated for unit size variations as shown in Table 33.

TABLE 33. POWER-RATING-SIZE COST ADJUSTMENT FACTORS

Unit Size, MW	Adjustment Factors	
	Capital Costs ($/kW)	Annual Operating Costs ($/ton)
1000	0.76	0.72
500	1.00	1.00
25	1.56	1.38

The above factors were applied in each of the disposal modes, as appropriate, for which estimates were made. However, in some instances, such as ponding, where land costs were a major capital cost item, the sizing factors were only applied to equipment investment costs. In all cases the operating cost factors were applied uniformly for each disposal mode.

Other specific baseline conditions for the cost estimates reported in this study are shown in Table 34.

5.2.2 Economics of Disposal Processes

The six FGD waste disposal processes selected for economic evaluation were:

a. Ponding of untreated wastes, using a flexible elastomeric liner and indigenous clay soil

b. Chemical treatment and landfill disposal

c. Mine disposal of untreated wastes

d. Ocean disposal of chemically treated wastes

These are discussed in the following sections.

5.2.2.1 Ponding of Untreated Wastes

A number of ponding alternatives encompassing a wide range of potentially acceptable modes included use of flexible elastomeric liners and indigenous clay (impervious) soil. The disposal site is assumed to be within 1 mile of the power plant.

5.2.2.1.1 Flexible Liner

A detailed cost analysis of the disposal of FGD wastes in ponds equipped with flexible liners was conducted in 1973 (13). Since

TABLE 34. REFERENCE CONDITIONS FOR COST ESTIMATES[a]

Dollar base:	July 1977
Plant and disposal site lifetime:	30 yr
Annual average operating hours:	4380 hr/yr (30-yr avg)
Average annual capital charges, 30-yr average:	18% of total capital investment
Cost of land used for disposal:	\$5000/acre, all land assumed purchased initially; sludge depth, 30 ft
Land depreciation:	Total depreciation in 30 yr, straight-line basis
Coal burned:	3.5% sulfur, 12,000 Btu/lb, 14% ash
SO_2 removal:	Limestone absorbent, 90% removal, 80% limestone utilization
Sludge generated:	2.5×10^5 short tons/yr (dry) (disposed waste assumed to contain 50% solids) for 500-MW plant

[a] Appendix A: Cases 31, 32, 33.

that time costing updates were made in 1974 and 1976 (29) using several liner materials considered to be representative of their price category, i.e., PVC (20-mil thickness) and Hypalon (30-mil thickness). The least expensive of these two materials, i.e., PVC-20, was selected for this analysis, and costs have been adjusted in accordance with the general guidelines listed in Section 5.2.1. Since previous work has shown that the optimum pond depth for this type of disposal is 30 feet, which is the depth at which pond construction and land costs are optimum with respect to the cost of liner material, it was used in this analysis.

Using current economic indices (31), it was determined that costs for this type of capital equipment have risen 11 percent since the previous estimates were made in January 1976. Therefore, the total capital investment for a lined pond having a 30-year capacity for a 1000-MW station, including 622 acres of land at $5000 per acre, is $18,757,200, or $18.76 per kilowatt. The adjusted investment costs for power plant sizes of 500 MW and 25 MW are shown in Table 35.

In estimating the annual costs it was assumed that the land used for ponded sludge disposal would depreciate totally over the 30-year filling period. This assumption was made because it has not been demonstrated that the land will be useful for any other purpose after the filling has been completed. Therefore, the annual capital charges were applied to the total capital investment, including land. The annual costs also include labor at an estimated $102,000 annual rate for operation and maintenance of the disposal site. For a 1000-MW station, the total average annual cost is $3,609,050 or $7.06 per dry ton of sludge. This annual cost is equivalent to 0.80 mills per kilowatt-hour. These operating costs and those for 500-MW and 25-MW stations are shown in Table 35.

5.2.2.1.2 Clay (Impervious) Indigenous Soil

The estimated costs for untreated FGD waste disposal in unlined ponds have been reported previously (13). This mode of disposal applies when the soil indigenous to the power plant is considered to be sufficiently impermeable to provide environmental protection to the groundwaters because of the negligible permeation of sludge liquors into the subsoil. The costing assumptions used for this disposal mode are the same as those used for the lined ponds, i.e., a sludge depth of 30 feet was assumed. A 15-foot sludge depth was determined to be the optimum costing point for this disposal mode, when considering the cost of land at $5000/acre versus the cost of construction; however, the total land area required is doubled, thereby reducing the practicality of using such a shallow depth.

TABLE 35. ESTIMATED COSTS FOR PONDING UNTREATED WASTES WITH FLEXIBLE 20-MIL PVC LINER

Unit Size, MW	Capital Investment		Average Annual Costs	
	$	$/kW	$/ton(dry)	mills/kWh
1000	18,757,200	18.76	7.25	0.80
500	11,901,200	23.80	9.01	1.02
25	768,533	30.74	17.30	2.19

Using the same economic indices previously applied for this type of construction (31), the capital costs were found to have increased 11 percent from January 1976 to July 1977. This, combined with the cost of land at $5000 per acre, results in a total capital investment of $12,477,300, or $12.48 per kilowatt. Estimates were made for plant sizes of 500 MW and 25 MW and are shown in Table 36. Adjustments for power plant size were made to construction only, because it was assumed that no benefits of size would apply to the cost of land required.

Again, it was assumed that the land used for disposal would depreciate totally over the 30-year service life of the plant. Therefore, average annual charges were applied to the total capital investment, and, for a 1000-MW plant, the average cost per dry ton of sludge was $4.89, or 0.54 mills per kilowatt-hour. Estimates made for 500-MW and 25-MW power plants are summarized in Table 36.

5.2.2.2 Chemical Treatment and Disposal

The cost of chemical treatment and disposal of FGD wastes in a landfill was estimated in March 1976 (21). At that time, estimates of total disposal costs were made for three chemical treatment processes, i.e., Dravo, IU Conversion Systems, and Chemfix, for a 1000-MW plant based on 1975 dollars. Using this work as a basis, cost estimates have been updated for the current conditions summarized in Section 5.2.1. Specific costing items that have been revised in the present estimates are the cost of land, now $5000 per acre (previously $1000 per acre), and adjustments in capital and operating costs as a function of power plant unit size.

The land necessary for sludge disposal totaled 460 acres, based on a sludge depth of 30 feet at a treated solids content of 60 percent by weight. It was also predicated on the disposal site being within 1 mile of the power plant. For a 1000-MW power plant adjusted to July 1977, the total capital

TABLE 36. ESTIMATED COSTS FOR DISPOSAL OF UNTREATED FGD WASTE IN PONDS WITH INDIGENOUS CLAY SOIL

Unit Size, MW	Capital Investment		Average Annual Costs	
	$	$/kW	$/ton(dry)	mills/kWh
1000	12,477,300	12.48	4.89	0.54
500	7,796,300	15.60	6.07	0.70
25	572,913	22.92	14.76	1.87

investment required for the assumed conditions is $13,595,440, or $13.60 per kilowatt. These estimates include an increase of approximately 13 percent in prices of capital equipment from July 1975.

The annual operating costs include labor, maintenance, materials, spare parts, operating power, the cost of transporting the sludge to the disposal site, and annual capital charges at a rate of 18 percent of the initial capital investment (Tables 33 and 34). The annual capital charges represent approximately half of the estimated annual costs. Based on current economic indices (31), the combined annual costs were increased by 13 percent, reflecting changes over the period of July 1975 to July 1977. For a 1000-MW power plant, the total average annual charges are estimated to be $9.70 per dry ton, or 1.06 mills per kilowatt-hour.

The capital and annual charges for chemical treatment and disposal, adjusted for power plant unit size, are summarized in Table 37.

5.2.2.3 Mine Disposal

The economics of disposal of untreated FGD wastes in coal mines has been reported (22) for both on-site and off-site disposal. Although on-site disposal (within 4 miles of the power plant) and off-site (within 200 miles of the plant) was reported, for purposes of this cost estimate the on-site mode was selected. Many key variables in off-site disposal costs, such as rail rates and special equipment, are quite site-specific and tend to make it difficult to arrive at a representative estimate. Both surface mine and underground mine disposal resulted in the same costs for the on-site case. For surface mine disposal, filtered untreated sludge mixed with fly ash would be transferred to an intermediate storage area by conveyor. The sludge would then be loaded into dump trucks and transported 4 miles to the disposal site, dumped, and covered with overburden. For underground disposal it was considered that the scrubber bleed would be pumped to a thickener area

TABLE 37. ESTIMATED COSTS FOR CHEMICAL TREATMENT AND DISPOSAL

Unit Size, MW	Capital Investment		Average Annual Costs	
	$	$/kW	$/ton(dry)	mills/kWh
1000	13,595,440	13.60	9.70	1.06
500	8,645,000	17.30	12.10	1.33
25	648,300	25.90	18.50	2.06

located near the mine mouth. The thickened underflow would then be pumped into boreholes at a solids content between 20 and 30 weight percent and the overflow would be pumped back to the scrubber system.

The investment required for either surface mine or underground mine disposal was reported to range up to 1.85 million dollars on a mid-1976 basis for a 500-MW plant. Correcting to July 1977 using current economic indices (31), the investment increases to $1,968,000. With this as a basis, estimates were made for the total investment required for both a 1000-MW and 25-MW station. These estimates are summarized in Table 38.

The operating costs for on-site disposal, on a dry ton basis, was reported as $3.50 per ton for a 500-MW plant. Allowing for increased prices since mid-1976 to July 1977, this value was increased to $3.71 per ton. Making adjustments for power plant unit size, estimates were also made for 1000-MW and 25-MW plants. These annual costs include average annual capital charges at 17 percent on a 30-year basis, interest, insurance, taxes, plant overhead, maintenance, labor, materials, and electric power. The total annual charges are summarized in Table 38.

5.2.2.4 Ocean Disposal

An analysis of ocean disposal of FGD sludge was reported in July 1976 (22) for power plants located on the eastern seaboard. Two potentially acceptable options were considered: (a) on-the-Continental-Shelf (within 25 nmi of the shoreline) disposal of treated (brick-like) wastes, and (b) off-shelf (100 nmi from shore) disposal of untreated sulfite-rich wastes. For each of these alternatives the cost of self propelled ships with bottom dump delivery was included. The reported study discussed chemical treatment for the on-shelf disposal, but did not include the cost of the treatment itself. However, in this estimate the cost of treatment was included since

TABLE 38. ESTIMATED COSTS FOR DISPOSAL OF UNTREATED FGD SLUDGE IN ON-SITE[a] SURFACE AND UNDERGROUND MINES

Unit Size, MW	Capital Investment		Average Annual Costs	
	$	$/kW	$/ton(dry)	mills/kWh
1000	2,982,000	2.98	2.67	0.27
500	1,968,000	3.94	3.71	0.37
25	153,000	6.14	5.08	0.51

[a] Power plant located within 4 miles of mine.

it was selected as the option for the economic analysis and should include all aspects of the disposal process. Also, since the dumping of sulfite-rich sludge would very likely be considered environmentally unacceptable, treatment was considered mandatory.

The on-shelf disposal operation would involve storage of treated sludge in stabilization ponds and subsequent transfer to barges for transport to the dumping site. For this costing analysis the on-shelf option using self-propelled ships was assumed, including provisions for sludge treatment and stabilization prior to disposal.

For a 500-MW plant, the investment for facilities, ships, and treatment equipment, on a July 1977 basis, was $17, 966, 800, or $35. 93 per kilowatt. Estimates for 1000-MW and 25-MW stations were made on a similar basis and include cost adjustments for purchasing in larger or smaller quantities. The estimates of capital costs for ocean dumping are summarized in Table 39.

The annual charges for operating at a 500-MW level, updated to July 1977 and supplemented with the costs associated with sludge treatment from Section 5.2.2.2, are presented in Table 39. In this case, however, the sludge treatment costs do not include the costs for a land disposal site and considers the need for a small area of approximately 2 acres for sludge stabilization. The resultant total average annual operating cost, for a 30-year average operating lifetime, is $18. 20 per dry ton, or 2. 28 mills per kilowatt-hour. Estimates for 1000-MW and 25-MW plants were also made and are summarized in Table 39.

TABLE 39. ESTIMATED COSTS FOR ON-SHELF[a] OCEAN DISPOSAL OF TREATED FGD WASTES

Unit Size, MW	Capital Investment		Average Annual Costs	
	$	$/kW	$/ton(dry)	mills/kWh
1000	24, 915, 000	24. 92	13. 10	1. 64
500	17, 967, 000	35. 93	18. 20	2. 28
25	1, 349, 000	53. 97	24. 89	3. 11

[a] Plant located on the eastern seaboard and disposal site located within 25 nautical miles of the coast.

it was selected as the option for the economic analysis and should include all aspects of the disposal process. Also, since the dumping of sulfite-rich sludge would very likely be considered environmentally unacceptable, treatment was considered mandatory.

The on-shelf disposal operation would involve storage of treated sludge in stabilization ponds and subsequent transfer to barges for transport to the dumping site. For this costing analysis the on-shelf option using self-propelled ships was assumed, including provisions for sludge treatment and stabilization prior to disposal.

For a 500-MW plant, the investment for facilities, ships, and treatment equipment, on a July 1977 basis, was $17, 966, 800, or $35. 93 per kilowatt. Estimates for 1000-MW and 25-MW stations were made on a similar basis and include cost adjustments for purchasing in larger or smaller quantities. The estimates of capital costs for ocean dumping are summarized in Table 39.

The annual charges for operating at a 500-MW level, updated to July 1977 and supplemented with the costs associated with sludge treatment from Section 5.2.2.2, are presented in Table 39. In this case, however, the sludge treatment costs do not include the costs for a land disposal site and considers the need for a small area of approximately 2 acres for sludge stabilization. The resultant total average annual operating cost, for a 30-year average operating lifetime, is $18.20 per dry ton, or 2.28 mills per kilowatt-hour. Estimates for 1000-MW and 25-MW plants were also made and are summarized in Table 39.

TABLE 39. ESTIMATED COSTS FOR ON-SHELF[a] OCEAN DISPOSAL OF TREATED FGD WASTES

Unit Size, MW	Capital Investment		Average Annual Costs	
	$	$/kW	$/ton(dry)	mills/kWh
1000	24,915,000	24.92	13.10	1.64
500	17,967,000	35.93	18.20	2.28
25	1,349,000	53.97	24.89	3.11

[a] Plant located on the eastern seaboard and disposal site located within 25 nautical miles of the coast.

5.2.2.5 Cost Comparison

A comparison of annual costs for the various forms of disposal is given in Table 40. Units of mills/kWh are used for ease of comparison. It should be noted that the disposal cost for gypsum includes the cost of forced oxidation of the sulfite slurry.

5.2.3 Economics of Utilization Processes

Whether nonregenerable or regenerable scrubbing processes are used, ash (which, for example, constitutes approximately 50 percent of the total nonregenerable systems dry waste, see Appendix C) would still require disposal at an estimated $3.50 per dry ton. For nonregenerable systems, the remaining 50 percent is available for production of useable gypsum; the by-products of regenerable systems are sulfur or sulfuric acid. The economics of these processes are discussed in the next two sections. Typical quantities from a 500-MW plant burning 3.5-percent-sulfur coal are provided in Table 41. Data for other fuel characteristics and FGD alternatives are given in Appendix A.

TABLE 40. DISPOSAL COST COMPARISONS[a, b] (MID-1977 BASIS) (mills/kWh)

Untreated Waste		Landfill-Chemical Treatment	Mine[c]	Ocean[d]	Gypsum[e]
Liner Added	Indigenous Clay				
1.02	0.70	1.33	0.37	2.28	1.39

[a] 500-MWe plant, 3.5% sulfur coal, 90% SO_2 removal. Disposal site within 1 mile from plant except as noted

[b] All wastes include ash

[c] Mine located 4 miles from plant; untreated waste

[d] Plant located on eastern seaboard and disposal site located on the Continental Shelf within 25 nautical miles from the coast; chemically treated waste

[e] Reference Table 42 for disposal in an indigenous clay-lined pond

TABLE 41. TYPICAL QUANTITIES OF WASTE AND BY-PRODUCTS PRODUCED FROM SO_2 SCRUBBER SYSTEMS[a] FOR 90-PERCENT SO_2 REMOVAL

	Waste[b] Tons/Yr Dry Basis	By-Product[c]	Quantity Produced Tons/Yr (Dry)
Limestone scrubbing, forced oxidation to gypsum[d]	1.15×10^5	ash-free gypsum	1.37×10^5
Magnesium Oxide (Case No. 38)	1.20×10^5	sulfuric acid	7.53×10^4
		sulfur	2.46×10^4
Wellman Lord (Case No. 41)	1.22×10^5	sulfuric acid	7.53×10^4
		sulfur	2.46×10^4

[a] 500-MW plant, 3.5%, 12,000 Btu/lb coal, 14%

[b] Primarily ash

[c] Quantities of either sulfuric acid and sulfur, but not both

[d] 100% absorbent utilization

5.2.3.1 Conversion to Gypsum

The cost of producing gypsum as a by-product from limestone 500-MWe scrubbing processes has been reported (12) for mid-1977. The estimate included the costs required to incorporate the forced oxidation processing to a basic lime or limestone scrubber system. To be useable, the gypsum cannot contain appreciable quantities of fly ash, therefore the power plant was assumed to have electrostatic precipitators. The cost of these was not charged to the cost of producing the gypsum. The capital equipment costs to produce gypsum in a new 500-MWe installation that scrubs flue gas from 3.5-percent-sulfur coal and removes 90 percent SO_2 is \$6,640,000, or \$13.28 per kilowatt. The estimates for a 1000- and 25-MW plant are shown in Table 42. The total operating cost, including annual charges on capital, for a typical 500-MW plant producing ash-free gypsum with 100-percent absorbent utilization is \$1,920,000, or \$14.03 per ton of dry gypsum produced. This also includes an estimated charge of \$3.50 per ton for disposal of the power plant ash. A summary of costs for the production and sale of gypsum, and disposal of ash, is given in Table 42.

TABLE 42. ESTIMATED COSTS FOR FORCED OXIDATION OF FLY-ASH-FREE FGD WASTES TO GYPSUM[a] (MID-1977 DOLLARS)

Unit Size MW	Capital Investment		Average Annual Costs for Gypsum Production Plus Ash Disposal, \$/ton Ash-Free Gypsum (dry)	Average Annual Costs for Producing Gypsum and Disposing of Ash, mills/kWh
	$\$\times10^6$	\$/kW		
1000	10.09	10.09	10.92	0.66
500[a]	6.64	13.28	14.03	0.88[b]
25	0.52	20.72	18.25	1.37

[a] Tons per year gypsum produced: 1.37×10^5
Tons per year ash: 1.15×10^5

[b] Equivalent to 0.70 mills/kWh for producing (only) a sludge containing gypsum and ash. This cost is included when computing disposal of gypsum sludge (with ash); e.g., for ponding in indigenous clay, add 0.70 mills/kWh (Ref. Table 40) to 0.70 for a 500-MW plant; totalling 1.40 mills/kWh.

5.2.3.2 Conversion to Sulfur or Sulfuric Acid

Cost projections for the Wellman-Lord and magnesium oxide regenerable processes (32, 33) include estimates for the complete systems since breakdowns into by-product costs are not available. In this context, a direct comparison with the costs for nonregenerable waste disposal is not possible. Published capital and operating cost estimates for regenerable processes are provided in Table 43.

5.2.4 Nationwide Cost Estimates of Various Disposal Processes

The estimated costs of disposing of nonregenerable SO_2 scrubber wastes produced during the 1978 to 1998 period are presented in Table 44. The waste quantities computed in Section 3.8.1 are for 90-percent SO_2 removal and for meeting emission standards of 1.2 and 0.5 lb SO_2 per million Btu heat input; the quantities are for the installations predicted for that 20-year period using the 500-MW reference plant outlined in Tables 21 and 22. Estimates of total annual costs (in mid-1977 dollars) for the five disposal

TABLE 43. REGENERABLE PROCESS COST DATA

Process	By-Product Produced			
	Sulfuric Acid		Sulfur	
	Capital Cost	Annual Operating	Capital Cost	Annual Operating
Wellman-Lord[a]	$\$55.5 \times 10^{6}$ (\$83/kW)	21.05×10^{6}[b] (3.4 mills/kWh)	$\$58.5 \times 10^{6}$ (\$87/kW)	$\$22.37 \times 10^{6}$[b] (3.7 mills/kWh)
Magnesium oxide[c]	$\$140.0 \times 10^{6}$ (\$98.5/kW)	44.8×10^{6}[d] (5.10 mills/kWh)		
Wellman-Lord[e]			$\$14.8 \times 10^{6}$ (\$129/kW)	6.01×10^{6} (8.1 mills/kWh)
Wellman-Lord[f]			$\$89.5 \times 10^{6}$ (\$127.9/kW)	7.24×10^{6} (5.0 mills/kWh)

[a] For 670-MW plant, 8100 Btu/lb, 1.3% S coal, 8000 hr/yr, 1976 dollars (Ref. 32).

[b] Credit for by-product not taken, estimated as \$60/ton for sulfur and \$24/ton for H_2SO_4.

[c] For 1420-MW plant, 6570 hr/yr, 1975 dollars (Ref. 33).

[d] Operating costs of acid plant not included. Assumed sales of acid will offset those costs.

[e] Northern Indiana Public Service, D.H. Mitchell Station No. 11, 177 dollars, 115 MW, 3.2-3.5% S coal, load factor 73.5% (Ref. 8).

[f] Public Service of New Mexico, San Juan Stations No. 1 and 2, 1977 dollars capital, operating 1978, 700 MW (net), 0.8% S coal, load factor 77% (Ref. 8).

TABLE 44. DISPOSAL COSTS FOR VARIOUS DISPOSAL METHODS: NATIONWIDE TOTALS[a]

Emission Standard	Year	Total Dry Waste,[b,f] tons × 10^6	Pond, Flex Liner	Total Annual Cost, Dollars in Millions (Mid-1977 dollars)					
				Pond,[c] Clay	Chemical Treat, Landfill	Mine, On-Site	Ocean, On-Shelf	Coal Wash Tailings, tons × 10^6	Wash[d] Tailings Disposal Costs
Unit cost \$/ton (dry basis)[e]			\$9.01	\$6.07	\$12.10	\$3.71	\$18.20	N/A	N/A
1.2 lb $SO_2/10^6$ Btu (80% SO_2 removal)	1980	18.38	165.60	111.57	222.40	68.21	334.61	N/A	N/A
	1983	36.00	324.36	218.52	435.60	133.56	665.20	N/A	N/A
	1988	67.02	603.85	406.82	810.94	248.65	1219.78	N/A	N/A
	1993	105.96	954.70	643.18	1282.12	393.10	1928.40	N/A	N/A
	1998	156.16	1407.00	947.89	1889.57	579.36	2842.13	N/A	N/A
0.6 lb $SO_2/10^6$ Btu (90% SO_2 removal)	1980	19.13	172.36	116.12	231.47	70.98	348.18	N/A	N/A
	1983	38.57	347.51	234.12	466.70	143.08	701.92	N/A	N/A
	1988	72.80	655.93	441.90	880.88	270.10	1325.01	N/A	N/A
	1993	115.77	1043.09	702.72	1400.82	429.50	2106.96	N/A	N/A
	1998	171.17	1542.24	1039.00	2071.16	635.03	3115.26	N/A	N/A
0.5 lb $SO_2/10^6$ Btu (85% SO_2 removal and 40% S removal by coal washing eastern coal)	1980	16.50	148.67	100.16	199.65	61.23	300.35	0.95	\$ 3.52
	1983	29.51	265.89	179.13	357.07	109.49	537.12	3.27	12.13
	1988	52.43	472.39	318.65	634.40	194.51	954.19	7.36	27.29
	1993	81.19	731.52	429.82	982.40	301.20	1477.60	12.48	46.31
	1998	118.27	1065.61	717.90	1431.07	438.79	2152.53	19.09	70.82

[a] 500-MW plant, 3.5% S eastern and 0.8% S western coal. For other conditions, see Tables 21 and 22.

[b] All wastes include ash.

[c] Clay is indigenous soil.

[d] May be added to sludge process costs to determine total disposal cost (disposal of tailings at mine assumed as \$3.50/ton dry)

[e] Assumes that the unit cost is unaffected by alternative emission standards.

[f] Totals are the annual quantities (tonnages or dollars) for the years shown for the new plants operating beginning with the base year of 1978.

methods described in Section 5.2.2 are shown. One of the least expensive disposal methods is ponding of untreated waste on indigenous soil. Assuming it were universally acceptable, it would result in expenditures of \$878 million, \$962 million, and \$665 million in the year 1998 to meet, respectively, the current NSPS standard of 1.2 lb $SO_2/10^6$ Btu, and the other alternatives, i.e., 90-percent SO_2 removal and 0.5 lb $SO_2/10^6$ Btu. Because of the overall lower sludge quantities having been produced as a result of the coal washing to meet the 0.5 lb $SO_2/10^6$ emission requirements (Section 3.8.1) that method results in a lower overall cost; the coal wash tailings having been disposed of at the mine. Correspondingly, if chemical treatment and landfill disposal of all the waste were assumed, it results in expenditures in the year 1998 of \$1.92 billion, \$2.10 billion, and \$1,45 billion[1] to meet current emission standards and the two alternative standards, respectively. Costs of ocean and mine disposal of all wastes are presented on a national scale solely to place those modes of disposal in perspective with the others. These costs assume all plants, in one instance, to be adjacent to the ocean on the eastern seaboard, and, in the other case, within a few miles of the mine; obviously all plants do not meet these criteria. However, these totals are presented for further consideration of regional and modal alternatives.

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[1] Cost of coal wash disposal not included (see Table 44).

REFERENCES

1. Meeting of 27 May 1977: J. W. Jones and K. Woodard (U.S. Environmental Protection Agency) and P. Leo and J. Rossoff (The Aerospace Corp.).

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APPENDIX A

EMISSIONS AND SOLID WASTE QUANTITIES FOR ALTERNATIVE CONTROL SYSTEM MODEL PLANTS

TABLE A-1. FORMAT FOR LIME AND LIMESTONE AND DOUBLE-ALKALI SCRUBBERS

```
 INPUT:
 CASE  #- PROCESS TITLES AND OPTIONS
 % SULFUR  FUEL,BTU   FUEL %    CAPACITY    FUEL BTU ABSORBENT % SO2 REM  % MOIST
  IN FUEL   PER LB     ASH         MW       PER KWH  UTILIZ,%  BY SCRUB.   IN WST

SULFITE-   DENSITY,  SODA ASH   PLANT      % SULFUR   DENSITY   % MOIST    FUEL
TO SULFATE WET WASTE MAKE UP  OPERATING   REMOVED  OF TAILING    IN       WASH
 RATIO      LB/FT3       %       HOURS      IN WASH    LB/FT3    TAILING    FACTOR


 OUTPUT:
  FUEL       TOTAL       SO2        SO2      ABSORBENT   SO2         SO2       SO2
 BURNED,    SULFUR     FORMED     REMOVED      USED    EMISSIONS EMISSIONS LB/M BTU
   T/H        T/H        T/H        T/H         T/H       T/H       LB/H

  ASH        PRECIP
 FORMED      CaCO3      CaSO3        CaSO4     % ASH     % CaCO3   % CaSO3   % CaSO4
   T/H        T/H        T/H          T/H    DRY WASTE DRY WASTE DRY WASTE DRY WAST

  TOTAL       TOTAL     TOTAL        TOTAL    TOTAL WET  TOTAL WET  TOTAL
 DRY WASTE WET WASTE DRY WASTE WET WASTE    VOL,FT3/   VOL,ACRE   BTU/HR
   T/H        T/H        T/Y         T/Y        YEAR     FEET/YEAR

* TAILING    TAILING    TAILING    TAILING    TAILING    TAILING   % ASH IN   AMT OF
  DRY,T/H    WET,T/H    DRY,T/Y    WET,T/Y    VOL,FT3/   VOL,ACRE   WASHED     FUEL
                                                YEAR     FEET/YEAR   FUEL

* SODA ASH % SODA ASH
    T/H      IN WASTE

 * These lines printed only if the options are invoked.

 T/H = TONS PER HOUR (SHORT TONS)
 T/Y = TONS PER YEAR (SHORT TONS)
 LB/H= POUNDS PER HOUR
 SODA ASH:FROM DOUBLE ALKALI OPTION

 TAILINGS: FROM COAL WASHING OPTION
```

TABLE A-2. FORMAT FOR MAGNESIUM OXIDE AND WELLMAN-LORD PROCESSES

```
INPUT:

CASE  #- PROCESS TITLES AND OPTIONS
% SULFUR  FUEL,BTU   FUEL %    CAPACITY    FUEL BTU     N/A     % SO2 REM    % MOIST
 IN FUEL   PER LB     ASH         MW       PER KWH              BY SCRUB.     IN WST

 REGEN    SOLID WST  ABSORB      PLANT-     H2SO4     SULFUR,%
 EFF,%    DENSITY,   MAKEUP   OPERATION    % CONV.     CONV.
           LB/FT3    PERCENT      H/Y

*% SULFUR DENSITY    PERCENT     FUEL
 REMOVED  OF TAILING MOIST IN    WASH
 IN WASH  LB/FT3     TAILING    FACTOR


OUTPUT:
 FUEL       TOTAL      SO2        SO2       SO2        SO2          TOTAL    SO2
BURNED,    SULFUR     FORMED    REMOVED  EMISSIONS  EMISSIONS     BTU/HR  LB/M BTU
  T/H        T/H        T/H        T/H       T/H       LB/H

DRY WASTE WET WASTE  DRY ASH   PROCESS     REGEN     % ASH,   % PROCESS     % REGEN
   T/H       T/H        T/H   SOLID DRY  SOLID DRY    DRY    SOLID,DRY    SOLID DRY
                              WASTE,T/H  WASTE,T/H   WASTE     WASTE        WASTE

  TOTAL      TOTAL     TOTAL    TOTAL WET   TOTAL     TOTAL       TOTAL      TOTAL
DRY WASTE WET WASTE  WET VOL   VOL, ACRE    H2SO4     H2SO4      SULFUR,    SULFUR,
   T/Y       T/Y     FT3/Y     FEET/YEAR     T/H       T/Y         T/H        T/Y

* TAILING   TAILING   TAILING    TAILING    TAILING   TAILING    % ASH IN    AMT OF
  DRY,T/H   WET,T/H   DRY,T/Y    WET,T/Y   VOL,FT3/  VOL,ACRE    WASHED      FUEL
                                              YEAR   FEET/YEAR    FUEL

* These lines printed only if the fuel wash option is invoked.


 T/H = TONS PER HOUR (SHORT TONS)
 T/Y = TONS PER YEAR (SHORT TONS)
 LB/H= POUNDS PER HOUR

 TAILINGS: FROM COAL WASHING OPTION


 PROCESS SOLID = ABSORBENT IN THE WASTE(DRY)
```

TABLE A-3. STUDY CASES: EMISSIONS AND WASTE QUANTITIES

```
CASE      1- LIME SCRUBBER
     3.50    12000.       14.00        1000.       8700.       90.00       80.00       50.00
   3.0:1.     88.60         0.0        4380.         0.0       80.00       15.00        2.00

OUTPUT:
  362.500    12.687      25.375       20.300      19.736       5.075      10150.       1.167
   50.750     3.524      30.688       13.639      51.470       3.574      31.123      13.833
   98.601   197.202 4.319E 05 8.637E 05 1.950E 07   447.604 8.700E 09

CASE      2- LIME SCRUBBER
     3.50    12000.       14.00         500.       9000.       90.00       80.00       50.00
   3.0:1.     88.60         0.0        4380.         0.0       80.00       15.00        2.00

OUTPUT:
  187.500     6.562      13.125       10.500      10.208       2.625       5250.       1.167
   26.250     1.823      15.873        7.055      51.470       3.574      31.123      13.833
   51.001   102.001 2.234E 05 4.468E 05 1.008E 07   231.520 4.500E 09

CASE      3- LIME SCRUBBER
     3.50    12000.       14.00          25.      10080.       90.00       80.00       50.00
   3.0:1.     88.60         0.0        4380.         0.0       80.00       15.00        2.00

OUTPUT:
   10.500     0.367       0.735        0.588       0.572       0.147        294.       1.167
    1.470     0.102       0.889        0.395      51.470       3.574      31.123      13.833
    2.856     5.712 1.251E 04 2.502E 04 5.648E 05    12.965 2.520E 08


CASE      4- LIMESTONE SCRUBBER
     3.50    12000.       14.00        1000.       8700.       80.00       80.00       50.00
   3.0:1.     88.60         0.0        4380.         0.0       80.00       15.00        2.00

OUTPUT:
  362.500    12.687      25.375       20.300      39.648       5.075      10150.       1.167
   50.750     7.93[illegible]      30.688       13.639      49.269       7.698      29.792      13.241
  103.007   206.013 4.512E 05 9.023E 05 2.037E 07   467.603 8.700E 09

CASE      5- LIMESTONE SCRUBBER
     3.50    12000.       14.00         500.       9000.       80.00       80.00       50.00
   3.0:1.     88.60         0.0        4380.         0.0       80.00       15.00        2.00

OUTPUT:
  187.500     6.562      13.125       10.500      20.508       2.625       5250.       1.167
   26.250     4.102      15.873        7.055      49.269       7.698      29.792      13.241
   53.279   106.558 2.334E 05 4.667E 05 1.054E 07   241.864 4.500E 09

CASE      6- LIMESTONE SCRUBBER
     3.50    12000.       14.00          25.      10080.       80.00       80.00       50.00
   3.0:1.     88.60         0.0        4380.         0.0       80.00       15.00        2.00

OUTPUT:
   10.500     0.367       0.735        0.588       1.148       0.147        294.       1.167
    1.470     0.230       0.889        0.395      49.269       7.698      29.792      13.241
    2.984     5.967 1.307E 04 2.614E 04 5.900E 05    13.544 2.520E 08
```

TABLE A-3. (Continued)

```
 CASE     7- DOUBLE ALKALI WITH LIME SCRUBBER
      3.50    12000.     14.00     1000.     8700.     95.00     80.00     50.00
    3.0:1.     88.60      3.00     4380.       0.0     80.00     15.00      2.00


 OUTPUT:
   362.500    12.687    25.375    20.300    18.697     5.075    10150.     1.167
    50.750     1.669    30.688    13.639    51.916     1.708    31.393    13.952
    97.755   195.510 4.282E 05 8.563E 05 1.933E 07   443.763 8.700E 09
     1.009     1.032

 CASE     8- DOUBLE ALKALI WITH LIME SCRUBBER
      3.50    12000.     14.00      500.     9000.     95.00     80.00     50.00
    3.0:1.     88.60      3.00     4380.       0.0     80.00     15.00      2.00


 OUTPUT:
   187.500     6.562    13.125    10.500     9.671     2.625     5250.     1.167
    26.250     0.863    15.873     7.055    51.916     1.708    31.393    13.952
    50.563   101.126 2.215E 05 4.429E 05 9.998E 06   229.533 4.500E 09
     0.522     1.032


 CASE     9- DOUBLE ALKALI WITH LIME SCRUBBER
      3.50    12000.     14.00       25.    10080.     95.00     80.00     50.00
    3.0:1.     88.60      3.00     4380.       0.0     80.00     15.00      2.00


 OUTPUT:
    10.500     0.367     0.735     0.588     0.542     0.147      294.     1.167
     1.470     0.048     0.889     0.395    51.916     1.708    31.393    13.952
     2.832     5.663 1.240E 04 2.480E 04 5.599E 05    12.854 2.520E 08
     0.029     1.032

 CASE    10- MAGNESIUM OXIDE
      3.50    12000.     14.00     1000.     8700.       0.0     80.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


 OUTPUT:
   362.500    12.687    25.375    20.300     5.075    10150. 8.700E 09     1.167
    52.780    81.200    50.750     0.381     1.649    96.154     0.721     3.125
 2.312E 05 3.557E 05 1.016E 07   233.278    29.530 1.293E 05     9.642 4.223E 04


 CASE    11- MAGNESIUM OXIDE
      3.50    12000.     14.00      500.     9000.       0.0     80.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


 OUTPUT:
   187.500     6.562    13.125    10.500     2.625     5250. 4.500E 09     1.167
    27.300    42.000    26.250     0.197     0.853    96.154     0.721     3.125
 1.196E 05 1.840E 05 5.256E 06   120.661    15.274 6.690E 04     4.987 2.185E 04


 CASE    12- MAGNESIUM OXIDE
      3.50    12000.     14.00       25.    10080.       0.0     80.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


 OUTPUT:
    10.500     0.367     0.735     0.588     0.147      294. 2.520E 08     1.167
     1.529     2.352     1.470     0.011     0.048    96.154     0.721     3.125
 6.696E 03 1.030E 04 2.943E 05     6.757     0.855 3.746E 03     0.279 1.223E 03
```

TABLE A-3. (Continued)

```
CASE    13-WELLMAN LORD
     3.50    12000.     14.00      1000.     8700.       0.0     80.00     35.00
    95.00     70.00      3.00      4380.    100.00    100.00


OUTPUT:
  362.500    12.687    25.375     20.300     5.075    10150. 8.700E 09     1.167
   53.598    82.459    50.750      1.199     1.649    94.686     2.237     3.077
2.348E 05 3.612E 05 1.032E 07    236.895    29.530 1.293E 05     9.642 4.223E 04


CASE    14-WELLMAN LORD
     3.50    12000.     14.00       500.     9000.       0.0     80.00 [illegible].00
    95.00     70.00      3.00      4380.    100.00    100.00


OUTPUT:
  187.500     6.562    13.125     10.500     2.625     5250. 4.500E 09     1.167
   27.723    42.651    26.250      0.620     0.853    94.686     2.237     3.077
1.214E 05 1.868E 05 5.337E 06    122.532    15.274 6.690E 04     4.987 2.185E 04


CASE    15-WELLMAN LORD
     3.50    12000.     14.00        25.    10080.       0.0     80.00     35.00
    95.00     70.00      3.00      4380.    100.00    100.00


OUTPUT:
   10.500     0.367     0.735      0.588     0.147      294. 2.520E 08     1.167
    1.553     2.388     1.470      0.035     0.048    94.686     2.237     3.077
6.800E 03 1.046E 04 2.989E 05      6.862     0.855 3.746E 03     0.279 1.223E 03


CASE    16- LIME SCRUBBER
     7.00    12000.     14.00      1000.     8700.     90.00     90.00     50.00
   3.0:1.     88.60       0.0      4380.       0.0     80.00     15.00      2.00


OUTPUT:
  362.500    25.375    50.750     45.675    44.406     5.075    10150.     1.167
   50.750     7.930    69.048     30.688    32.036     5.006    43.587    19.372
  158.415   316.830 6.939E 05 1.388E 06 3.133E 07    719.132 8.700E 09


CASE    17- LIME SCRUBBER
     7.00    12000.     14.00       500.     9000.     90.00     90.00     50.00
   3.0:1.     88.60       0.0      4380.       0.0     80.00     15.00      2.00


OUTPUT:
  187.500    13.125    26.250     23.625    22.969     2.625     5250.     1.167
   26.250     4.102    35.714     15.873    32.036     5.006    43.587    19.372
   81.939   163.878 3.589E 05 7.178E 05 1.620E 07    371.965 4.500E 09


CASE    18- LIME SCRUBBER
     7.00    12000.     14.00        25.    10080.     90.00     90.00     50.00
   3.0:1.     88.60       0.0      4380.       0.0     80.00     15.00      2.00


OUTPUT:
   10.500     0.735     1.470      1.323     1.286     0.147      294.     1.167
    1.470     0.230     2.000      0.889    32.036     5.006    43.587    19.372
    4.589     9.177 2.010E 04 4.020E 04 9.074E 05     20.830 2.520E 08
```

TABLE A-3. (Continued)

```
CASE     19- LIMESTONE SCRUBBER
    7.00    12000.     14.00       1000.      8700.      80.00      90.00      50.00
  3.0:1.     88.60       0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
  362.500    25.375    50.750     45.675     89.209      5.075     10150.      1.167
   50.750    17.842    69.048     30.688     30.150     10.599     41.020     18.231
  168.327   336.654 7.373E 05 1.475E 06 3.329E 07    764.128 8.700E 09


CASE     20- LIMESTONE SCRUBBER
    7.00    12000.     14.00        500.      9000.      80.00      90.00      50.00
  3.0:1.     88.60       0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
  187.500    13.125    26.250     23.625     46.143      2.625      5250.      1.167
   26.250     9.229    35.714     15.873     30.150     10.599     41.020     18.231
   87.066   174.132 3.813E 05 7.627E 05 1.722E 07    395.239 4.500E 09


CASE     21- LIMESTONE SCRUBBER
    7.00    12000.     14.00         25.     10080.      80.00      90.00      50.00
  3.0:1.     88.60       0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
   10.500     0.735     1.470      1.323      2.584      0.147       294.      1.167
    1.470     0.517     2.000      0.889     30.150     10.599     41.020     18.231
    4.876     9.751 2.136E 04 4.271E 04 9.641E 05     22.133 2.520E 08


CASE     22-  NO SCRUBBER
    0.80    13500.      6.00        500.      9000.       0.0        0.0       35.00
  3.0:1.     70.00       0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
  166.667     1.333     2.667      0.0        0.0        2.667      5333.      1.185
   10.000     0.0       0.0        0.0      100.000      0.0        0.0        0.0
   10.000    15.385 4.380E 04 6.738E 04 1.925E 06     44.198 4.500E 09


CASE     23-  NO SCRUBBER
    0.80    13500.      6.00         25.     10080.       0.0        0.0       35.00
  3.0:1.     70.00       0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
    9.333     0.075     0.149      0.0        0.0        0.149       299.      1.185
    0.560     0.0       0.0        0.0      100.000      0.0        0.0        0.0
    0.560     0.862 2.453E 03 3.774E 03 1.078E 05      2.475 2.520E 08


CASE     24-  NO SCRUBBER
    0.60    10000.      8.00        500.      9000.       0.0        0.0       35.00
  3.0:1.     70.00       0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
  225.000     1.350     2.700      0.0        0.0        2.700      5400.      1.200
   18.000     0.0       0.0        0.0      100.000      0.0        0.0        0.0
   18.000    27.692 7.884E 04 1.213E 05 3.465E 06     79.557 4.500E 09
```

TABLE A-3. (Continued)

```
CASE   241-   NO  SCRUBBER
    0.40     8000.       6.00       500.      9000.       0.0        0.0       35.00
  3.0:1.     70.00       0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
  281.250     1.125      2.250      0.0        0.0       2.250      4500.      1.000
   16.875    0.0        0.0        0.0       100.000     0.0        0.0        0.0
   16.875   25.962 7.391E 04 1.137E 05 3.249E 06     74.584 4.500E 09


CASE    25-   NO  SCRUBBER
    0.60    10000.       8.00        25.     10080.       0.0        0.0       35.00
  3.0:1.     70.00       0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
   12.600    0.076      0.151      0.0        0.0       0.151       302.      1.200
    1.008    0.0        0.0        0.0       100.000    0.0         0.0        0.0
    1.008    1.551 4.415E 03 6.792E 03 1.941E 05      4.455 2.520E 06


CASE   251-   NO SCRUBBER
    0.40     8000.       6.00        25.     10080.       0.0        0.0       35.00
  3.0:1.     70.00       0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
   15.750    0.063      0.126      0.0        0.0       0.126       252.      1.000
    0.945    0.0        0.0        0.0       100.000    0.0        0.0        0.0
    0.945    1.454 4.139E 03 6.368E 03 1.819E 05      4.177 2.520E 06


 CASE    26- COAL WASH WITH LIME SCRUBBER
     3.50     13200.     14.00       500.       9000.      90.00      65.00      50.00
   3.0:1.      88.60      0.0       4380.      40.00      80.00      15.00       2.00


 OUTPUT:
   170.455     3.580      7.159      4.653      4.524      2.506      5011.      1.114
    15.770     0.808      7.035      3.127     58.977      3.021     26.309     11.693
    26.739    53.477 1.171E 05 2.342E 05 5.287E 06    121.382 4.500E 09
     9.336    10.984 4.089E 04 4.811E 04 1.203E 06     27.611      9.252    179.329


CASE    27- COAL WASH WITH LIMESTONE SCRUBBER
    3.50     13200.     14.00       500.       9000.      80.00      65.00      50.00
  3.0:1.      88.60      0.0       4380.      40.00      80.00      15.00       2.00


OUTPUT:
  170.455     3.580      7.159      4.653      9.089      2.506      5011.      1.114
   15.770     1.818      7.035      3.127     56.831      6.551     25.351     11.267
   27.749    55.497 1.215E 05 2.431E 05 5.487E 06    125.966 4.500E 09
    9.336    10.984 4.089E 04 4.811E 04 1.203E 06     27.611      9.252    179.329

CASE    28- LIME SCRUBBER
    3.50     12000.     14.00      1000.       8700.      90.00      90.00      50.00
  3.0:1.      88.60      0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
  362.500    12.687     25.375     22.837     22.203      2.538      5075.      0.583
   50.750     3.965     34.524     15.344     48.526      3.791     33.011     14.672
  104.583   209.165 4.581E 05 9.161E 05 2.068E 07    474.757 8.700E 09
```

TABLE A-3. (Continued)

```
CASE    29- LIME SCRUBBER
      3.50    12000.     14.00      500.     9000.       90.00     90.00       50.00
    3.0:1.     88.60       0.0     4380.       0.0       80.00     15.00        2.00


OUTPUT:
   187.500     6.562    13.125    11.812    11.484       1.313     2625.       0.583
    26.250     2.051    17.857     7.937    48.526       3.791    33.011      14.672
    54.094   108.189 2.369E 05 4.739E 05 1.070E 07     245.564 4.500E 09


CASE    30- LIME SCRUBBER
      3.50    12000.     14.00       25.    10080.       90.00     90.00       50.00
    3.0:1.     88.60       0.0     4380.       0.0       80.00     15.00        2.00


OUTPUT:
    10.500     0.367     0.735     0.661     0.643       0.074      147.       0.583
     1.470     0.115     1.000     0.444    48.526       3.791    33.011      14.672
     3.029     6.059 1.327E 04 2.654E 04 5.990E 05      13.752 2.520E 08


CASE    31- LIMESTONE SCRUBBER
      3.50    12000.     14.00     1000.     8700.       80.00     90.00       50.00
    3.0:1.     88.60       0.0     4380.       0.0       80.00     15.00        2.00


OUTPUT:
   362.500    12.687    25.375    22.837    44.604       2.538     5075.       0.583
    50.750     8.921    34.524    15.344    46.331       8.144    31.517      14.008
   109.539   219.077 4.798E 05 9.596E 05 2.166E 07     497.255 8.700E 09


CASE    32- LIMESTONE SCRUBBER
      3.50    12000.     14.00      500.     9000.       80.00     90.00       50.00
    3.0:1.     88.60       0.0     4380.       0.0       80.00     15.00        2.00


OUTPUT:
   187.500     6.562    13.125    11.812    23.071       1.313     2625.       0.583
    26.250     4.614    17.857     7.937    46.331       8.144    31.518      14.008
    56.658   113.316 2.482E 05 4.963E 05 1.120E 07     257.201 4.500E 09

CASE    33- LIMESTONE SCRUBBER
      3.50    12000.     14.00       25.    10080.       80.00     90.00       50.00
    3.0:1.     88.60       0.0     4380.       0.0       80.00     15.00        2.00


OUTPUT:
    10.500     0.367     0.735     0.661     1.292       0.074      147.       0.583
     1.470     0.258     1.000     0.444    46.331       8.144    31.517      14.008
     3.173     6.346 1.390E 04 2.779E 04 6.274E 05      14.403 2.520E 08


CASE    34- DOUBLE ALKALI WITH LIME SCRUBBER
      3.50    12000.     14.00     1000.     8700.       95.00     90.00       50.00
    3.0:1.     88.60      3.00     4380.       0.0       80.00     15.00        2.00


OUTPUT:
   362.500    12.687    25.375    22.837    21.034       2.538     5075.       0.583
    50.750     1.878    34.524    15.344    48.972       1.812    33.314      14.806
   103.630   207.261 4.539E 05 9.078E 05 2.049E 07     470.435 8.700E 09
     1.135     1.095
```

TABLE A-3. (Continued)

```
CASE    35- DOUBLE ALKALI WITH LIME SCRUBBER
      3.50    12000.     14.00      500.     9000.     95.00     90.00     50.00
    3.0:1.     88.60      3.00     4380.       0.0     80.00     15.00      2.00


OUTPUT:
   187.500     6.562    13.125    11.812    10.880     1.313     2625.     0.583
    26.250     0.971    17.857     7.937    48.972     1.812    33.314    14.806
    53.602   107.204 2.348E 05 4.696E 05 1.060E 07   243.329 4.500E 09
     0.587     1.095

CASE    36- DOUBLE ALKALI WITH LIME SCRUBBER
      3.50    12000.     14.00       25.    10080.     95.00     90.00     50.00
    3.0:1.     88.60      3.00     4380.       0.0     80.00     15.00      2.00


OUTPUT:
    10.500     0.367     0.735     0.661     0.609     0.074      147.     0.583
     1.470     0.054     1.000     0.444    48.972     1.812    33.314    14.806
     3.002     6.003 1.315E 04 2.629E 04 5.936E 05    13.626 2.520E 08
     0.033     1.095


CASE    37- MAGNESIUM OXIDE
      3.50    12000.     14.00     1000.     8700.       0.0     90.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


OUTPUT:
   362.500    12.687    25.375    22.837     2.538     5075. 8.700E 09     0.583
    53.034    81.590    50.750     0.428     1.856    95.694     0.807     3.499
 2.323E 05 3.574E 05 1.021E 07   234.399    33.221 1.455E 05    10.848 4.751E 04


CASE    38- MAGNESIUM OXIDE
      3.50    12000.     14.00      500.     9000.       0.0     90.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


OUTPUT:
   187.500     6.562    13.125    11.812     1.313     2625. 4.500E 09     0.583
    27.431    42.202    26.250     0.221     0.960    95.694     0.807     3.499
 1.201E 05 1.848E 05 5.281E 06   121.241    17.183 7.526E 04     5.611 2.458E 04

CASE    39- MAGNESIUM OXIDE
      3.50    12000.     14.00       25.    10080.       0.0     90.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


OUTPUT:
    10.500     0.367     0.735     0.661     0.074      147. 2.520E 08     0.583
     1.536     2.363     1.470     0.012     0.054    95.694     0.807     3.499
 6.728E 03 1.035E 04 2.958E 05     6.769     0.962 4.215E 03     0.314 1.376E 03


CASE    40-WELLMAN LORD
      3.50    12000.     14.00     1000.     8700.       0.0     90.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


OUTPUT:
   362.500    12.687    25.375    22.837     2.538     5075. 8.700E 09     0.583
    53.954    83.007    50.750     1.349     1.856    94.061     2.500     3.439
 2.363E 05 3.636E 05 1.039E 07   238.468    33.221 1.455E 05    10.848 4.751E 04
```

TABLE A-3. (Continued)

```
CASE    41-WELLMAN LORD
      3.50    12000.     14.00      500.     9000.       0.0     90.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


OUTPUT:
   187.500     6.562    13.125    11.812     1.313     2625. 4.500E 09     0.583
    27.907    42.934    26.250     0.698     0.960    94.061     2.500     3.439
 1.222E 05 1.881E 05 5.373E 06   123.346    17.183 7.526E 04     5.611 2.458E 04

CASE    42-WELLMAN LORD
      3.50    12000.     14.00       25.    10080.       0.0     90.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


OUTPUT:
    10.500     0.367     0.735     0.661     0.074      147. 2.520E 08     0.583
     1.563     2.404     1.470     0.039     0.054    94.061     2.500     3.439
 6.845E 03 1.053E 04 3.009E 05     6.907     0.962 4.215E 03     0.314 1.376E 03


CASE    43- LIME SCRUBBER
      7.00    12000.     14.00     1000.     8700.     90.00     90.00     50.00
    3.0:1.     88.60       0.0     4380.       0.0     80.00     15.00      2.00


OUTPUT:
   362.500    25.375    50.750    45.675    44.406     5.075    10150.     1.167
    50.750     7.930    69.048    30.688    32.036     5.006    43.587    19.372
   158.415   316.830 6.939E 05 1.388E 06 3.133E 07   719.132 8.700E 09


CASE    44- LIME SCRUBBER
      7.00    12000.     14.00      500.     9000.     90.00     90.00     50.00
    3.0:1.     88.60       0.0     4380.       0.0     80.00     15.00      2.00


OUTPUT:
   187.500    13.125    26.250    23.625    22.969     2.625     5250.     1.167
    26.250     4.102    35.714    15.873    32.036     5.006    43.587    19.372
    81.939   163.878 3.589E 05 7.178E 05 1.620E 07   371.965 4.500E 09



CASE    45- LIME SCRUBBER
      7.00    12000.     14.00       25.    10080.     90.00     90.00     50.00
    3.0:1.     88.60       0.0     4380.       0.0     80.00     15.00      2.00


OUTPUT:
    10.500     0.735     1.470     1.323     1.286     0.147      294.     1.167
     1.470     0.230     2.000     0.889    32.036     5.006    43.587    19.372
     4.589     9.177 2.010E 04 4.020E 04 9.074E 05    20.830 2.520E 08


CASE    46- LIMESTONE SCRUBBER
      7.00    12000.     14.00     1000.     8700.     80.00     90.00     50.00
    3.0:1.     88.60       0.0     4380.       0.0     80.00     15.00      2.00


OUTPUT:
   362.500    25.375    50.750    45.675    89.209     5.075    10150.     1.167
    50.750    17.842    69.048    30.688    30.150    10.599    41.020    16.231
   168.327   336.654 7.373E 05 1.475E 06 3.329E 07   764.128 8.700E 09
```

TABLE A-3. (Continued)

```
CASE    47- LIMESTONE SCRUBBER
    7.00    12000.      14.00       500.      9000.      80.00      90.00      50.00
   3.0:1.    88.60       0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
  187.500    13.125     26.250     23.625     46.143      2.625      5250.      1.167
   26.250     9.229     35.714     15.873     30.150     10.599     41.020     18.231
   87.066   174.132 3.813E 05 7.627E 05 1.722E 07   395.239 4.500E 09

CASE    48- LIMESTONE SCRUBBER
    7.00    12000.      14.00        25.     10080.      80.00      90.00      50.00
   3.0:1.    88.60       0.0       4380.       0.0       80.00      15.00       2.00


OUTPUT:
   10.500     0.735      1.470      1.323      2.584      0.147       294.      1.167
    1.470     0.517      2.000      0.889     30.150     10.599     41.020     18.231
    4.876     9.751 2.136E 04 4.271E 04 9.641E 05    22.133 2.520E 08


CASE    49- DOUBLE ALKALI WITH LIME SCRUBBER
    7.00    12000.      14.00      1000.      8700.      95.00      90.00      50.00
   3.0:1.    88.60       3.00      4380.       0.0       80.00      15.00       2.00


OUTPUT:
  362.500    25.375     50.750     45.675     42.069      5.075     10150.      1.167
   50.750     3.756     69.048     30.686     32.426      2.400     44.117     19.607
  156.511   313.022 6.855E 05 1.371E 06 3.095E 07   710.488 8.700E 09
    2.269     1.450


CASE    50- DOUBLE ALKALI WITH LIME SCRUBBER
    7.00    12000.      14.00       500.      9000.      95.00      90.00      50.00
   3.0:1.    88.60       3.00      4380.       0.0       80.00      15.00       2.00
              .
OUTPUT:
  187.500    13.125     26.250     23.625     21.760      2.625      5250.      1.167
   26.250     1.943     35.714     15.873     32.426      2.400     44.117     19.607
   80.954   161.908 3.546E 05 7.092E 05 1.601E 07   367.494 4.500E 09
    1.174     1.450

CASE    51- DOUBLE ALKALI WITH LIME SCRUBBER
    7.00    12000.      14.00        25.     10080.      95.00      90.00      50.00
   3.0:1.    88.60       3.00      4380.       0.0       80.00      15.00       2.00


OUTPUT:
   10.500     0.735      1.470      1.323      1.219      0.147       294.      1.167
    1.470     0.109      2.000      0.889     32.426      2.400     44.117     19.607
    4.533     9.067 1.986E 04 3.971E 04 8.965E 05    20.580 2.520E 08
    0.066     1.450


CASE    52- MAGNESIUM OXIDE
    7.00    12000.      14.00      1000.      8700.       0.0       90.00      35.00
   95.00     70.00       3.00      4380.     100.00     100.00


OUTPUT:
  362.500    25.375     50.750     45.675      5.075     10150. 8.700E 09      1.167
   55.317    85.104     50.750      0.856      3.711     91.743      1.548      6.709
2.423E 05 3.728E 05 1.065E 07   244.493     66.443 2.910E 05    21.696 9.503E 04
```

TABLE A-3. (Continued)

```
CASE    53- MAGNESIUM OXIDE
      7.00    12000.     14.00      500.     9000.       0.0     90.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


OUTPUT:
   187.500    13.125    26.250    23.625     2.625     5250. 4.500E 09     1.167
    28.612    44.019    26.250     0.443     1.920    91.743     1.548     6.709
 1.253E 05 1.928E 05 5.509E 06   126.462    34.367 1.505E 05    11.222 4.915E 04


CASE    54- MAGNESIUM OXIDE
      7.00    12000.     14.00       25.    10080.       0.0     90.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


OUTPUT:
    10.500     0.735     1.470     1.323     0.147      294. 2.520E 08     1.167
     1.602     2.465     1.470     0.025     0.107    91.743     1.548     6.709
 7.018E 03 1.080E 04 3.085E 05     7.082     1.925 8.430E 03     0.628 2.752E 03


CASE    55-WELLMAN LORD
      7.00    12000.     14.00     1000.     8700.       0.0     90.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


OUTPUT:
   362.500    25.375    50.750    45.675     5.075    10150. 8.700E 09     1.167
    57.159    87.936    50.750     2.698     3.711    88.788     4.720     6.493
 2.504E 05 3.852E 05 1.100E 07   252.631    66.443 2.910E 05    21.696 9.503E 04


CASE    56-WELLMAN LORD
      7.00    12000.     14.00      500.     9000.       0.0     90.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


OUTPUT:
   187.500    13.125    26.250    23.625     2.625     5250. 4.500E 09     1.167
    29.565    45.484    26.250     1.395     1.920    88.788     4.720     6.493
 1.295E 05 1.992E 05 5.692E 06   130.671    34.367 1.505E 05    11.222 4.915E 04


CASE    57-WELLMAN LORD
      7.00    12000.     14.00       25.    10080.       0.0     90.00     35.00
     95.00     70.00      3.00     4380.    100.00    100.00


OUTPUT:
    10.500     0.735     1.470     1.323     0.147      294. 2.520E 08     1.167
     1.656     2.547     1.470     0.078     0.107    88.788     4.720     6.493
 7.252E 03 1.116E 04 3.188E 05     7.318     1.925 8.430E 03     0.628 2.752E 03


CASE    58- LIME SCRUBBER
      0.80    10000.      8.00      500.     9000.     90.00     90.00     50.00
    3.0:1.     88.60       0.0     4380.       0.0     80.00     15.00      2.00


OUTPUT:
   225.000     1.800     3.600     3.240     3.150     0.360      720.     0.160
    18.000     0.562     4.898     2.177    70.210     2.194    19.105     8.491
    25.637    51.275 1.123E 05 2.246E 05 5.070E 06   116.382 4.500E 09
```

TABLE A-3. (Continued)

```
CASE   581- LIME SCRUBBER
    0.80       8000.       6.00        500.      9000.       90.00      90.00       50.00
  3.0:1.       88.60       0.0        4380.       0.0        80.00      15.00        2.00


OUTPUT:
 281.250       2.250      4.500       4.050      3.937       0.450       900.       0.200
  16.875       0.703      6.122       2.721     63.868       2.661     23.172      10.299
  26.422      52.843 1.157E 05 2.315E 05 5.225E 06    119.942 4.500E 09


  CASE    59- LIME SCRUBBER
      0.80     10000.       8.00         25.     10080.      90.00      90.00       50.00
    3.0:1.      88.60       0.0        4380.       0.0       80.00      15.00        2.00


  OUTPUT:
    12.600      0.101      0.202       0.181      0.176      0.020        40.       0.160
     1.008      0.031      0.274       0.122     70.210      2.194     19.105       8.491
     1.436      2.871 6.288E 03 1.256E 04 2.839E 05          6.517 2.520E 08


  CASE   591- LIME SCRUBBER
      0.80      8000.       6.00         25.     10080.      90.00      90.00       50.00
    3.0:1.      88.60       0.0        4380.       0.0       80.00      15.00        2.00


  OUTPUT:
    15.750      0.126      0.252       0.227      0.220      0.025        50.       0.200
     0.945      0.039      0.343       0.152     63.868      2.661     23.172      10.299
     1.480      2.959 6.481E 03 1.296E 04 2.926E 05          6.717 2.520E 08

  CASE    60- LIMESTONE SCRUBBER
      0.80     10000.       8.00        500.      9000.      80.00      90.00       50.00
    3.0:1.      88.60       0.0        4380.       0.0       80.00      15.00        2.00


  OUTPUT:
   225.000      1.800      3.600       3.240      6.328      0.360       720.       0.160
    18.000      1.266      4.898       2.177     68.336      4.805     18.595       8.264
    26.340     52.681 1.154E 05 2.307E 05 5.209E 06        119.573 4.500E 09


  CASE   601- LIMESTONE SCRUBBER
      0.80      8000.       6.00        500.      9000.      80.00      90.00       50.00
    3.0:1.      88.60       0.0        4380.       0.0       80.00      15.00        2.00


  OUTPUT:
   281.250      2.250      4.500       4.050      7.910      0.450       900.       0.200
    16.875      1.582      6.122       2.721     61.812      5.795     22.426       9.967
    27.301     54.601 1.196E 05 2.392E 05 5.398E 06        123.932 4.500E 09


CASE   602- LIMESTONE SCRUBBER
    0.80       8000.       6.00        500.      9000.       80.00      40.00       50.00
  3.0:1.       88.60       0.0        4380.       0.0        80.00      15.00        2.00


OUTPUT:
 281.250       2.250      4.500       1.800      3.516       2.700      5400.       1.200
  16.875       0.703      2.721       1.209     78.457       3.269     12.651       5.623
  21.509      43.017 9.421E 04 1.884E 05 4.253E 06      97.639 4.500E 09
```

TABLE A-3. (Continued)

```
CASE   603- LIMESTONE SCRUBBER
    0.80     10000.       8.00        500.      9000.      80.00      25.00      50.00
  3.0:1.      88.60        0.0       4380.        0.0      80.00      15.00       2.00

OUTPUT:
 225.000      1.800      3.600      0.900      1.758      2.700      5400.      1.200
  18.000      0.352      1.361      0.605     88.597      1.730      6.697      2.976
  20.317     40.633  8.899E 04 1.780E 05  4.017E 06     92.229  4.500E 09

CASE  6001- LIMESTONE SCRUBBER
    3.50     12000.      14.00        200.      9200.      80.00      80.00      50.00
  3.0:1.      88.60        0.0       4380.        0.0      80.00      15.00       2.00

OUTPUT:
  76.667      2.683      5.367      4.293      8.385      1.073      2147.      1.167
  10.733      1.677      6.490      2.885     49.259      7.698     29.792     13.241
  21.785     43.571  9.542E 04 1.908E 05  4.308E 06     98.895  1.840E 09

CASE    61- LIMESTONE SCRUBBER
    0.80     10000.       8.00         25.     10080.      80.00      90.00      50.00
  3.0:1.      88.60        0.0       4380.        0.0      80.00      15.00       2.00

OUTPUT:
  12.600      0.101      0.202      0.181      0.354      0.020        40.      0.160
   1.008      0.071      0.274      0.122     68.336      4.805     18.595      8.264
   1.475      2.950  6.461E 03 1.292E 04  2.917E 05      6.696  2.520E 08

CASE   611- LIMESTONE SCRUBBER
    0.80      8000.       6.00         25.     10080.      80.00      90.00      50.00
  3.0:1.      88.60        0.0       4380.        0.0      80.00      15.00       2.00

OUTPUT:
  15.750      0.126      0.252      0.227      0.443      0.025        50.      0.200
   0.945      0.089      0.343      0.152     61.812      5.795     22.426      9.967
   1.529      3.058  6.696E 03 1.339E 04  3.023E 05      6.940  2.520E 08

CASE    62- LIME SCRUBBER
    0.80     10000.       8.00        500.      9000.      90.00      70.00      50.00
  3.0:1.      88.60        0.0       4380.        0.0      80.00      15.00       2.00

OUTPUT:
 225.000      1.800      3.600      2.520      2.450      1.080      2160.      0.480
  18.000      0.437      3.810      1.693     75.188      1.827     15.913      7.072
  23.940     47.880  1.049E 05 2.097E 05  4.734E 06    108.677  4.500E 09

CASE   621- LIME SCRUBBER
    0.80      8000.       6.00        500.      9000.      90.00      75.00      50.00
  3.0:1.      88.60        0.0       4380.        0.0      80.00      15.00       2.00

OUTPUT:
 281.250      2.250      4.500      3.375      3.281      1.125      2250.      0.500
  16.875      0.586      5.102      2.268     67.961      2.360     20.547      9.132
  24.831     49.661  1.088E 05 2.175E 05  4.910E 06    112.719  4.500E 09
```

TABLE A-3. (Continued)

```
CASE    63- LIME SCRUBBER
        0.80    10000.       8.00        25.     10080.      90.00      70.00      50.00
      3.0:1.     88.60        0.0      4380.        0.0      80.00      15.00       2.00


OUTPUT:
      12.600     0.101      0.202      0.141      0.137      0.060       121.      0.460
       1.008     0.024      0.213      0.095     75.188      1.627     15.913      7.072
       1.341     2.681  5.872E 03  1.174E 04  2.651E 05      6.086  2.520E 08


CASE   631- LIME SCRUBBER
        0.80     8000.       6.00        25.     10080.      90.00      75.00      50.00
      3.0:1.     88.60        0.0      4380.        0.0      80.00      15.00       2.00


OUTPUT:
      15.750     0.126      0.252      0.189      0.164      0.063       126.      0.500
       0.945     0.033      0.286      0.127     67.961      2.360     20.547      9.132
       1.391     2.781  6.090E 03  1.218E 04  2.750E 05      6.312  2.520E 08


CASE    64- LIMESTONE SCRUBBER
        0.80    10000.       8.00       500.      9000.      80.00      70.00      50.00
      3.0:1.     88.60        0.0      4380.        0.0      80.00      15.00       2.00


OUTPUT:
     225.000     1.800      3.600      2.520      4.922      1.080      2160.      0.480
      18.000     0.984      3.810      1.693     73.508      4.020     15.557      6.914
      24.487    48.974  1.073E 05  2.145E 05  4.842E 06    111.160  4.500E 09

CASE   641- LIMESTONE SCRUBBER
        0.80     8000.       6.00       500.      9000.      80.00      75.00      50.00
      3.0:1.     88.60        0.0      4380.        0.0      80.00      15.00       2.00


OUTPUT:
     281.250     2.250      4.500      3.375      6.592      1.125      2250.      0.500
      16.875     1.318      5.102      2.268     66.013      5.157     19.959      8.871
      25.563    51.126  1.120E 05  2.239E 05  5.055E 06    116.044  4.500E 09


CASE    65- LIMESTONE SCRUBBER
        0.80    10000.       8.00        25.     10080.      80.00      70.00      50.00
      3.0:1.     88.60        0.0      4380.        0.0      80.00      15.00       2.00


OUTPUT:
      12.600     0.101      0.202      0.141      0.276      0.060       121.      0.480
       1.008     0.055      0.213      0.095     73.508      4.020     15.557      6.914
       1.371     2.743  6.006E 03  1.201E 04  2.712E 05      6.225  2.520E 08

CASE   651- LIMESTONE SCRUBBER
        0.80     8000.       6.00        25.     10080.      80.00      75.00      50.00
      3.0:1.     88.60        0.0      4380.        0.0      80.00      15.00       2.00


OUTPUT:
      15.750     0.126      0.252      0.189      0.369      0.063       126.      0.500
       0.945     0.074      0.286      0.127     66.013      5.157     19.959      8.871
       1.432     2.863  6.270E 03  1.254E 04  2.831E 05      6.498  2.520E 08
```

TABLE A-3. (Continued)

```
CASE    66- COAL WASH WITH LIME SCRUBBER
    3.50     13200.      14.00        500.      9000.      90.00      85.00      50.00
  3.0:1.      88.60        0.0       4380.      40.00      80.00      15.00       2.00


OUTPUT:
  170.455     3.580      7.159      6.085      5.916      1.074      2148.      0.477
   15.770     1.056      9.199      4.089     52.367      3.508     30.548     13.577
   30.114    60.228 1.319E 05 2.638E 05 5.955E 06    136.703 4.500E 09
    9.336    10.984 4.089E 04 4.811E 04 1.203E 06     27.611      9.252    179.329

    CASE    661- LIMESTONE SCRUBBER
        3.50     12000.      14.00        500.      9000.      80.00      91.50      50.00
      3.0:1.      88.60        0.0       4380.        0.0      80.00      15.00       2.00


    OUTPUT:
      187.500     6.562     13.125     12.009     23.456      1.116      2231.      0.496
       26.250     4.691     18.155      8.069     45.920      8.206     31.759     14.115
       57.165   114.329 2.504E 05 5.008E 05 1.130E 07    259.502 4.500E 09

CASE    67- COAL WASH WITH LIME SCRUBBER
    3.50     13200.      14.00         25.     10080.      90.00      85.00      50.00
  3.0:1.      88.60        0.0       4380.      40.00      80.00      15.00       2.00


OUTPUT:
    9.545     0.200      0.401      0.341      0.331      0.060       120.      0.477
    0.883     0.059      0.515      0.229     52.367      3.508     30.548     13.577
    1.686     3.373 7.386E 03 1.477E 04 3.335E 05      7.655 2.520E 08
    0.523     0.615 2.290E 03 2.694E 03 6.735E 04      1.546      9.252     10.042

    CASE    68- COAL WASH WITH LIMESTONE SCRUBBER
        3.50     13200.      14.00        500.      9000.      80.00      85.00      50.00
      3.0:1.      88.60        0.0       4380.      40.00      80.00      15.00       2.00


    OUTPUT:
      170.455     3.580      7.159      6.085     11.885      1.074      2148.      0.477
       15.770     2.377      9.199      4.089     50.167      7.562     29.265     13.006
       31.434    62.869 1.377E 05 2.754E 05 6.216E 06    142.698 4.500E 09
        9.336    10.984 4.089E 04 4.811E 04 1.203E 06     27.611      9.252    179.329

    CASE    69- COAL WASH WITH LIMESTONE SCRUBBER
        3.50     13200.      14.00         25.     10080.      80.00      85.00      50.00
      3.0:1.      88.60        0.0       4380.      40.00      80.00      15.00       2.00


    OUTPUT:
        9.545     0.200      0.401      0.341      0.666      0.060       120.      0.477
        0.883     0.133      0.515      0.229     50.167      7.562     29.265     13.006
        1.760     3.521 7.710E 03 1.542E 04 3.481E 05      7.991 2.520E 08
        0.523     0.615 2.290E 03 2.694E 03 6.735E 04      1.546      9.252     10.042

    CASE    70- COAL WASH WITH LIME SCRUBBER
        7.00     13200.      14.00        500.      9000.      90.00      95.00      50.00
      3.0:1.      88.60        0.0       4380.      40.00      80.00      15.00       2.00


    OUTPUT:
      170.455     7.159     14.318     13.602     13.224      0.716      1432.      0.318
        6.752     2.362     20.563      9.139     17.395      6.084     52.976     23.545
       38.815    77.630 1.700E 05 3.400E 05 7.675E 06    176.203 4.500E 09
       19.597    23.055 8.583E 04 1.010E 05 2.525E 06     57.955      3.961    188.203
```

TABLE A-3. (Continued)

```
CASE   701- COAL WASH WITH LIME SCRUBBER
    7.00    13200.      14.00       500.      9000.      90.00      92.50      50.00
  3.0:1.     88.60        0.0      4380.      40.00      80.00      15.00       2.00


OUTPUT:
  170.455      7.159     14.318     13.244     12.876      1.074      2148.      0.477
    6.752      2.299     20.022      8.899     17.781      6.056     52.728     23.435
   37.971     75.943 1.663E 05 3.326E 05 7.509E 06    172.373 4.500E 09
   19.597     23.055 8.583E 04 1.010E 05 2.525E 06     57.955      3.961    188.203

  CASE   702- LIMESTONE SCRUBBER
      7.00    12000.      14.00       500.      9000.      80.00      96.00      50.00
    3.0:1.     88.60        0.0      4380.        0.0      80.00      15.00       2.00


  OUTPUT:
    187.500     13.125     26.250     25.200     49.219      1.050      2100.      0.467
     26.250      9.844     38.095     16.931     28.808     10.803     41.808     18.581
     91.120    182.240 3.991E 05 7.982E 05 1.802E 07    413.644 4.500E 09

  CASE     71- COAL WASH WITH LIMESTONE SCRUBBER
      7.00    13200.      14.00       500.      9000.      80.00      95.00      50.00
    3.0:1.     88.60        0.0      4380.      40.00      80.00      15.00       2.00


  OUTPUT:
    170.455      7.159     14.318     13.602     26.567      0.716      1432.      0.318
      6.752      5.313     20.563      9.139     16.165     12.721     49.232     21.881
     41.767     83.534 1.829E 05 3.659E 05 8.259E 06    189.603 4.500E 09
     19.597     23.055 8.583E 04 1.010E 05 2.525E 06     57.955      3.961    188.203

CASE   711- COAL WASH WITH LIMESTONE SCRUBBER
    7.00    13200.      14.00       500.      9000.      80.00      92.50      50.00
  3.0:1.     88.60        0.0      4380.      40.00      80.00      15.00       2.00


OUTPUT:
  170.455      7.159     14.318     13.244     25.868      1.074      2148.      0.477
    6.752      5.174     20.022      8.899     16.530     12.666     49.018     21.786
   40.846     81.691 1.789E 05 3.578E 05 8.077E 06    185.420 4.500E 09
   19.597     23.055 8.583E 04 1.010E 05 2.525E 06     57.955      3.961    188.203

CASE   712- COAL WASH WITH LIMESTONE SCRUBBER
    7.00    13200.      14.00       500.      9000.      90.00      92.50      50.00
  3.0:1.     88.60        0.0      4380.      40.00      80.00      15.00       2.00


OUTPUT:
  170.455      7.159     14.318     13.244     22.994      1.074      2148.      0.477
    6.752      2.299     20.022      8.899     17.761      6.055     52.728     23.435
   37.971     75.943 1.663E 05 3.326E 05 7.509E 06    172.373 4.500E 09
   19.597     23.055 8.583E 04 1.010E 05 2.525E 06     57.955      3.961    188.203

CASE   713- COAL WASH WITH LIMESTONE SCRUBBER
    7.00    12900.      14.00       500.      9000.      80.00      93.50      50.00
  3.0:1.     88.60        0.0      4380.      30.00      80.00      15.00       2.00


OUTPUT:
  174.419      8.547     17.093     15.982     31.215      1.111      2222.      0.494
   11.641      6.243     24.160     10.738     22.055     11.828     45.774     20.344
   52.782    105.564 2.312E 05 4.624E 05 1.044E 07    239.606 4.500E 09
   14.685     17.276 6.432E 04 7.567E 04 1.892E 06     43.428      6.674    168.040
```

TABLE A-3. (Continued)

```
CASE   714- COAL WASH WITH LIMESTONE SCRUBBER
     7.00    12600.     14.00      500.     9000.     80.00     94.50     50.00
   3.0:1.     88.60       0.0     4380.     20.00     80.00     15.00      2.00


OUTPUT:
  178.571    10.000    20.000    18.900    36.914     1.100     2200.     0.489
   16.521     7.383    28.571    12.698    25.349    11.328    43.839    19.484
   65.173   130.347 2.855E 05 5.709E 05 1.289E 07   295.857 4.500E 09
    9.781    11.507 4.284E 04 5.040E 04 1.260E 06    28.926     9.252   187.868


CASE   715- COAL WASH WITH LIMESTONE SCRUBBER
     7.00    13200.     14.00      500.     9000.     80.00     92.00     50.00
   3.0:1.     88.60       0.0     4380.     40.00     80.00     15.00      1.50


OUTPUT:
  170.455     7.159    14.318    13.173    25.728     1.145     2291.     0.509
   11.376     5.146    19.913     8.850    25.121    11.362    43.973    19.544
   45.286    90.571 1.984E 05 3.967E 05 8.955E 06   205.576 4.500E 09
   14.351    16.883 6.286E 04 7.395E 04 1.849E 06    42.441     6.674   183.766


CASE   716- COAL WASH WITH LIMESTONE SCRUBBER
     7.00    13200.     14.00      500.     9000.     80.00     92.00     50.00
   3.0:1.     88.60       0.0     4380.     40.00     80.00     15.00      1.00


OUTPUT:
  170.455     7.159    14.318    13.173    25.728     1.145     2291.     0.509
   15.770     5.146    19.913     8.850    31.743    10.358    40.084    17.815
   49.679    99.358 2.176E 05 4.352E 05 9.824E 06   225.521 4.500E 09
    9.336    10.984 4.089E 04 4.811E 04 1.203E 06    27.611     9.252   179.329
```

APPENDIX B

NATIONWIDE SUMMARY OF PREDICTED TOTAL WASTES PRODUCED BY NONREGENERABLE SCRUBBING PROCESSES

The following applies to Tables B-1a through B-3d:

a. See Tables 21 and 22 for baseline conditions, pages 62 and 63.

b. "Annual" refers to those quantities, i.e., tons, acres, acre-ft, generated or required in each specific year denoted.

c. "Total annual" refers to the sum of each specific year with the previous years, up to and including 1978.

d. See also Figure 6, page 37.

TABLE B-1a. 1.2-LB $SO_2/10^6$ BTU: 55 PERCENT EASTERN COAL

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6016.
1979	15544.	31.1	18.65	4.354	8.997	4514.	188.	389.	11660.
1980	21101.	42.2	23.21	5.417	14.414	5617.	234.	623.	16602.
1981	15639.	31.3	17.20	4.015	18.429	4163.	173.	796.	23806.
1982	17854.	35.7	19.64	4.584	23.013	4753.	198.	994.	29827.
1983	18075.	36.2	19.89	4.642	27.655	4813.	201.	1195.	35843.
1984	16319.	32.6	17.95	4.190	31.845	4344.	181.	1376.	41273.
1985	19515.	39.0	21.47	5.010	36.855	5195.	216.	1592.	47766.
1986	18000.	36.0	19.80	4.621	41.476	4792.	200.	1792.	53756.
1987	17000.	34.0	18.70	4.365	45.841	4525.	189.	1980.	59413.
1988	20000.	40.0	22.00	5.135	50.975	5324.	222.	2202.	66066.
1989	19000.	38.0	20.90	4.878	55.854	5058.	211.	2413.	72390.
1990	21000.	42.0	23.10	5.392	61.245	5590.	233.	2646.	79376.
1991	28000.	56.0	30.80	7.189	68.434	7454.	311.	2956.	88695.
1992	22000.	44.0	24.20	5.648	74.082	5856.	244.	3201.	96015.
1993	24000.	48.0	26.40	6.162	80.244	6389.	266.	3467.	104002.
1994	30000.	60.0	33.00	7.702	87.946	7986.	333.	3799.	113984.
1995	24000.	48.0	26.40	6.162	94.108	6389.	266.	4066.	121970.
1996	30000.	60.0	33.00	7.702	101.810	7986.	333.	4398.	131953.
1997	30000.	60.0	33.00	7.702	109.512	7986.	333.	4731.	141935.
1998	33000.	66.0	36.30	8.472	117.985	8785.	366.	5097.	152916.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 - 35: 65
   1979 - 40: 60
   1980-1998 - 45: 55
2. ACRES REQUIRED - ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb)
   1978-1998 - 2.334 x 10^5 tons @ 80% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Eastern) - 242

(continued)

TABLE B-1a. 1.2-LB $SO_2/10^6$ BTU: 55 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2825.
1980	21101.	42.2	18.99	1.789	3.970	1654.	77.	171.	5143.
1981	15639.	31.3	14.06	1.326	5.296	1374.	57.	229.	6861.
1982	17854.	35.7	16.07	1.514	6.810	1569.	65.	294.	8822.
1983	18079.	36.2	16.27	1.533	8.343	1589.	66.	360.	10808.
1984	16319.	32.6	14.69	1.384	9.726	1434.	60.	420.	12601.
1985	19515.	39.0	17.56	1.655	11.381	1715.	71.	491.	14744.
1986	18000.	36.0	16.20	1.526	12.907	1582.	66.	557.	16721.
1987	17000.	34.0	15.30	1.441	14.349	1494.	62.	620.	18569.
1988	20000.	40.0	18.00	1.696	16.044	1758.	73.	693.	20786.
1989	19000.	38.0	17.10	1.611	17.655	1670.	70.	762.	22873.
1990	21000.	42.0	18.90	1.781	19.436	1845.	77.	839.	25180.
1991	28000.	56.0	25.20	2.374	21.810	2461.	103.	942.	28255.
1992	22000.	44.0	19.80	1.865	23.675	1933.	81.	1022.	30672.
1993	24000.	48.0	21.60	2.035	25.710	2109.	88.	1110.	33308.
1994	30000.	60.0	27.00	2.544	28.254	2636.	110.	1220.	36603.
1995	24000.	48.0	21.60	2.035	30.289	2109.	88.	1308.	39240.
1996	30000.	60.0	27.00	2.544	32.832	2636.	110.	1418.	42535.
1997	30000.	60.0	27.00	2.544	35.376	2636.	110.	1528.	45831.
1998	33000.	66.0	29.70	2.798	38.174	2900.	121.	1649.	49455.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 45: 55
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - WESTERN COAL (0.8% Sulfur, 6% Ash, 8000 Btu/lb)
   = 9.421×10^4 tons @ 40% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   = 97.64

(concluded)

TABLE B-1a. 1.2-LB $SO_2/10^6$ BTU: 55 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL			WESTERN COAL			NATIONWIDE		
			ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	TOTAL ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.997	389.	11660.	2.181	94.	2825.	11.	483.	14485.
1980	21101.	42.2	14.414	623.	18682.	3.970	171.	5143.	18.	794.	23825.
1981	15639.	31.3	18.429	796.	23886.	5.296	229.	6861.	24.	1025.	30747.
1982	17854.	35.7	23.013	994.	29827.	6.810	294.	8822.	30.	1288.	38649.
1983	18079.	36.2	27.655	1195.	35843.	8.343	360.	10808.	36.	1555.	46651.
1984	16319.	32.6	31.845	1376.	41273.	9.726	420.	12601.	42.	1796.	53873.
1985	19515.	39.0	36.855	1592.	47766.	11.381	491.	14744.	48.	2084.	62511.
1986	18000.	36.0	41.476	1792.	53756.	12.907	557.	16721.	54.	2349.	70477.
1987	17000.	34.0	45.841	1980.	59413.	14.349	620.	16589.	60.	2600.	76002.
1988	20000.	40.0	50.975	2202.	66068.	16.044	693.	20785.	67.	2895.	86853.
1989	19000.	38.0	55.854	2413.	72390.	17.655	762.	22873.	74.	3175.	95263.
1990	21000.	42.0	61.245	2646.	79376.	19.436	839.	25180.	81.	3485.	104557.
1991	28000.	56.0	68.434	2956.	88695.	21.810	942.	28255.	90.	3898.	116950.
1992	22000.	44.0	74.082	3201.	96015.	23.675	1022.	30672.	98.	4223.	126687.
1993	24000.	48.0	80.244	3467.	104002.	25.710	1110.	33308.	106.	4577.	137310.
1994	30000.	60.0	87.946	3799.	113984.	28.254	1220.	36603.	116.	5020.	150586.
1995	24000.	48.0	94.108	4066.	121970.	30.289	1308.	39240.	124.	5374.	161210.
1996	30000.	60.0	101.810	4398.	131953.	32.832	1418.	42535.	135.	5816.	174488.
1997	30000.	60.0	109.512	4731.	141935.	35.376	1528.	45831.	145.	6259.	187766.
1998	33000.	66.0	117.985	5097.	152916.	38.174	1649.	49455.	156.	6746.	202371.

TABLE B-1b. 1.2-LB $SO_2/10^6$ BTU: 85 PERCENT EASTERN COAL

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6016.
1979	15544.	31.1	18.65	4.354	8.997	4514.	188.	389.	11660.
1980	21101.	42.2	35.87	8.372	17.369	8681.	362.	750.	22512.
1981	15639.	31.3	26.59	6.205	23.574	6434.	268.	1018.	30554.
1982	17854.	35.7	30.35	7.084	30.659	7345.	306.	1325.	39736.
1983	18079.	36.2	30.73	7.173	37.832	7436.	310.	1634.	49033.
1984	16319.	32.6	27.74	6.475	44.307	6714.	280.	1914.	57425.
1985	19515.	39.0	33.18	7.743	52.050	8028.	335.	2249.	67461.
1986	18000.	36.0	30.60	7.142	59.192	7405.	309.	2557.	76717.
1987	17000.	34.0	28.90	6.745	65.937	6994.	291.	2849.	85459.
1988	20000.	40.0	34.00	7.936	73.873	8228.	343.	3191.	95745.
1989	19000.	38.0	32.30	7.539	81.412	7817.	326.	3517.	105515.
1990	21000.	42.0	35.70	8.332	89.744	8639.	360.	3877.	116315.
1991	28000.	56.0	47.60	11.110	100.854	11519.	480.	4357.	130714.
1992	22000.	44.0	37.40	8.729	109.583	9051.	377.	4734.	142027.
1993	24000.	48.0	40.80	9.523	119.106	9874.	411.	5146.	154369.
1994	30000.	60.0	51.00	11.903	131.009	12342.	514.	5660.	169797.
1995	24000.	48.0	40.80	9.523	140.532	9874.	411.	6071.	182139.
1996	30000.	60.0	51.00	11.903	152.435	12342.	514.	6586.	197567.
1997	30000.	60.0	51.00	11.903	164.339	12342.	514.	7100.	212994.
1998	33000.	66.0	56.10	13.094	177.432	13576.	566.	7665.	229965.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 15: 85
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb)
   1978-1998 = 2.334 x 10^5 tons @ 80% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Eastern) = 242

(continued)

TABLE B-1b. 1.2-LB $SO_2/10^6$ BTU: 85 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2825.
1980	21101.	42.2	6.33	0.596	2.777	616.	26.	120.	3596.
1981	15639.	31.3	4.69	0.442	3.219	458.	19.	139.	4170.
1982	17854.	35.7	5.36	0.505	3.724	523.	22.	161.	4624.
1983	18079.	36.2	5.42	0.511	4.235	530.	22.	183.	5466.
1984	16319.	32.6	4.90	0.461	4.696	478.	20.	203.	6084.
1985	19515.	39.0	5.85	0.552	5.247	572.	24.	227.	6796.
1986	18000.	36.0	5.40	0.509	5.756	527.	22.	249.	7457.
1987	17000.	34.0	5.10	0.480	6.237	498.	21.	269.	8080.
1988	20000.	40.0	6.00	0.565	6.802	566.	24.	294.	8812.
1989	19000.	38.0	5.70	0.537	7.339	557.	23.	317.	9508.
1990	21000.	42.0	6.30	0.594	7.932	615.	26.	343.	10277.
1991	28000.	56.0	8.40	0.791	8.724	820.	34.	377.	11302.
1992	22000.	44.0	6.60	0.622	9.346	644.	27.	404.	12107.
1993	24000.	48.0	7.20	0.678	10.024	703.	29.	433.	12906.
1994	30000.	60.0	9.00	0.848	10.872	879.	37.	469.	14065.
1995	24000.	48.0	7.20	0.678	11.550	703.	29.	499.	14963.
1996	30000.	60.0	9.00	0.848	12.398	879.	37.	535.	16062.
1997	30000.	60.0	9.00	0.848	13.246	879.	37.	572.	17160.
1998	33000.	66.0	9.90	0.933	14.179	967.	40.	612.	18369.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 15 : 85
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - WESTERN COAL (0.8% Sulfur, 6% Ash, 8000 Btu/lb)
   = 9.421 x 10^4 tons @ 40% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   = 97.64

(continued)

TABLE B-1b. 1.2-LB $SO_2/10^6$ BTU: 85 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL			WESTERN COAL			NATIONWIDE		
			ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	TOTAL ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.997	389.	11660.	2.181	94.	2825.	11.	483.	14486.
1980	21101.	42.2	17.369	750.	22512.	2.777	120.	3596.	20.	870.	26109.
1981	15639.	31.3	23.574	1018.	30554.	3.219	139.	4170.	27.	1157.	34725.
1982	17854.	35.7	30.659	1325.	39736.	3.724	161.	4824.	34.	1485.	44560.
1983	18079.	36.2	37.832	1634.	49033.	4.235	183.	5486.	42.	1817.	54519.
1984	16319.	32.6	44.307	1914.	57425.	4.696	203.	6084.	49.	2117.	63509.
1985	19515.	39.0	52.050	2249.	67461.	5.247	227.	6796.	57.	2475.	74259.
1986	18000.	36.0	59.192	2557.	76717.	5.756	249.	7457.	65.	2806.	84174.
1987	17000.	34.0	65.937	2849.	85459.	6.237	269.	8080.	72.	3118.	93539.
1988	20000.	40.0	73.873	3191.	95745.	6.802	294.	8812.	81.	3485.	104557.
1989	19000.	38.0	81.412	3517.	105515.	7.339	317.	9508.	89.	3834.	115023.
1990	21000.	42.0	89.744	3877.	116315.	7.932	343.	10277.	98.	4220.	126591.
1991	28000.	56.0	100.854	4357.	130714.	8.724	377.	11302.	110.	4734.	142016.
1992	22000.	44.0	109.583	4734.	142027.	9.346	404.	12107.	119.	5138.	154135.
1993	24000.	48.0	119.106	5146.	154369.	10.024	433.	12986.	129.	5579.	167355.
1994	30000.	60.0	131.009	5660.	169797.	10.872	469.	14065.	142.	6129.	183862.
1995	24000.	48.0	140.532	6071.	182139.	11.550	499.	14963.	152.	6570.	197102.
1996	30000.	60.0	152.435	6586.	197567.	12.398	535.	16062.	165.	7121.	213628.
1997	30000.	60.0	164.339	7100.	212994.	13.246	572.	17160.	178.	7672.	230155.
1998	33000.	66.0	177.432	7665.	229965.	14.179	612.	18369.	192.	8276.	248333.

TABLE B-1c. 1.2-LB $SO_2/10^6$ BTU: 70 PERCENT EASTERN COAL

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6018.
1979	15544.	31.1	18.65	4.354	8.997	4514.	188.	389.	11660.
1980	21101.	42.2	29.54	6.895	15.892	7149.	298.	687.	20597.
1981	15639.	31.3	21.89	5.110	21.002	5298.	221.	907.	27220.
1982	17854.	35.7	25.00	5.834	26.836	6049.	252.	1159.	34781.
1983	18079.	36.2	25.31	5.907	32.743	6125.	255.	1415.	42436.
1984	16319.	32.6	22.85	5.332	38.076	5529.	230.	1645.	49349.
1985	19515.	39.0	27.32	6.377	44.452	6612.	275.	1920.	57613.
1986	18000.	36.0	25.20	5.882	50.334	6098.	254.	2175.	65237.
1987	17000.	34.0	23.80	5.555	55.889	5760.	240.	2415.	72436.
1988	20000.	40.0	28.00	6.535	62.424	6776.	282.	2697.	80906.
1989	19000.	38.0	26.60	6.208	68.633	6437.	268.	2965.	88953.
1990	21000.	42.0	29.40	6.862	75.495	7115.	296.	3262.	97846.
1991	28000.	56.0	39.20	9.149	84.644	9486.	395.	3657.	109704.
1992	22000.	44.0	30.80	7.189	91.833	7454.	311.	3967.	119021.
1993	24000.	48.0	33.60	7.842	99.675	8131.	339.	4306.	129185.
1994	30000.	60.0	42.00	9.803	109.476	10164.	424.	4730.	141890.
1995	24000.	48.0	33.60	7.842	117.320	8131.	339.	5068.	152054.
1996	30000.	60.0	42.00	9.803	127.123	10164.	424.	5492.	164759.
1997	30000.	60.0	42.00	9.803	136.925	10164.	424.	5915.	177464.
1998	33000.	66.0	46.20	10.783	147.709	11180.	466.	6381.	191440.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 • 35: 65
   1979 • 40: 60
   1980-1998 • 30: 70
2. ACRES REQUIRED • ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb)
   1978-1998 • 2.334 x 10^5 tons @ 80% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Eastern) • 242

(continued)

TABLE B-1c. 1.2-LB $SO_2/10^6$ BTU: 70 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2625.
1980	21101.	42.2	12.66	1.193	3.373	1236.	52.	146.	4370.
1981	15639.	31.3	9.38	0.884	4.257	916.	38.	184.	5516.
1982	17854.	35.7	10.71	1.009	5.267	1046.	44.	227.	6823.
1983	18079.	36.2	10.85	1.022	6.289	1059.	44.	272.	8147.
1984	16319.	32.6	9.79	0.922	7.211	956.	40.	311.	9342.
1985	19515.	39.0	11.71	1.103	8.314	1143.	48.	359.	10771.
1986	18000.	36.0	10.80	1.017	9.332	1055.	44.	403.	12069.
1987	17000.	34.0	10.20	0.961	10.293	996.	41.	444.	13334.
1988	20000.	40.0	12.00	1.131	11.423	1172.	49.	493.	14799.
1989	19000.	38.0	11.40	1.074	12.497	1113.	46.	540.	16190.
1990	21000.	42.0	12.60	1.187	13.684	1230.	51.	591.	17728.
1991	28000.	56.0	16.80	1.583	15.267	1640.	68.	659.	19779.
1992	22000.	44.0	13.20	1.244	16.510	1289.	54.	713.	21390.
1993	24000.	48.0	14.40	1.357	17.867	1406.	59.	772.	23147.
1994	30000.	60.0	18.00	1.696	19.563	1758.	73.	845.	25344.
1995	24000.	48.0	14.40	1.357	20.919	1406.	59.	903.	27102.
1996	30000.	60.0	18.00	1.696	22.615	1758.	73.	977.	29298.
1997	30000.	60.0	18.00	1.696	24.311	1758.	73.	1050.	31495.
1998	33000.	66.0	19.80	1.865	26.176	1933.	81.	1130.	33912.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 30: 70
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - WESTERN COAL
   (0.8% Sulfur, 6% Ash, 8000 Btu/lb)
   = 9.421 x 10^4 tons @ 40% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   = 97.64

(continued)

TABLE B-1c. 1.2-LB $SO_2/10^6$ BTU: 70 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL			WESTERN COAL			NATIONWIDE		
			ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	TOTAL ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.997	389.	11660.	2.181	94.	2825.	11.	483.	14486.
1980	21101.	42.2	15.892	687.	20597.	3.373	146.	4370.	19.	832.	24967.
1981	15639.	31.3	21.002	907.	27220.	4.257	184.	5516.	25.	1091.	32736.
1982	17854.	35.7	26.836	1159.	34781.	5.267	227.	6823.	32.	1387.	41604.
1983	18079.	36.2	32.743	1415.	42438.	6.289	272.	8147.	39.	1686.	50585.
1984	16319.	32.6	38.076	1645.	49349.	7.211	311.	9342.	45.	1956.	58691.
1985	19515.	39.0	44.452	1920.	57613.	8.314	359.	10771.	53.	2279.	68385.
1986	18000.	36.0	50.334	2175.	65237.	9.332	403.	12069.	60.	2578.	77326.
1987	17000.	34.0	55.889	2415.	72436.	10.293	444.	13334.	66.	2859.	85770.
1988	20000.	40.0	62.424	2697.	80906.	11.423	493.	14799.	74.	3190.	95705.
1989	19000.	38.0	68.633	2965.	88953.	12.497	540.	16190.	81.	3505.	105143.
1990	21000.	42.0	75.495	3262.	97846.	13.684	591.	17728.	89.	3852.	115574.
1991	28000.	56.0	84.644	3657.	109704.	15.267	659.	19779.	100.	4316.	129483.
1992	22000.	44.0	91.833	3967.	119021.	16.510	713.	21390.	108.	4680.	140411.
1993	24000.	48.0	99.675	4306.	129185.	17.867	772.	23147.	118.	5078.	152333.
1994	30000.	60.0	109.478	4730.	141890.	19.563	845.	25344.	129.	5574.	167234.
1995	24000.	48.0	117.320	5068.	152054.	20.919	903.	27102.	138.	5972.	179156.
1996	30000.	60.0	127.123	5492.	164759.	22.615	977.	29298.	150.	6469.	194058.
1997	30000.	60.0	136.925	5915.	177464.	24.311	1050.	31495.	161.	6965.	208960.
1998	33000.	66.0	147.709	6381.	191440.	26.176	1130.	33912.	174.	7512.	225352.

TABLE B-1d. 1.2-LB $SO_2/10^6$ BTU: 25 PERCENT EASTERN COAL

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6018.
1979	15544.	31.1	18.65	4.354	8.997	4514.	188.	389.	11660.
1980	21101.	42.2	10.55	2.462	11.459	2553.	106.	495.	14852.
1981	15639.	31.3	7.82	1.825	13.284	1892.	79.	574.	17217.
1982	17854.	35.7	8.93	2.084	15.368	2160.	90.	664.	19918.
1983	18079.	36.2	9.04	2.110	17.478	2188.	91.	755.	22652.
1984	16319.	32.6	8.16	1.904	19.382	1975.	82.	837.	25121.
1985	19515.	39.0	9.76	2.277	21.660	2361.	98.	936.	28072.
1986	18000.	36.0	9.00	2.101	23.760	2178.	91.	1026.	30795.
1987	17000.	34.0	8.50	1.984	25.744	2057.	86.	1112.	33366.
1988	20000.	40.0	10.00	2.334	28.078	2420.	101.	1213.	36391.
1989	19000.	38.0	9.50	2.217	30.295	2299.	96.	1309.	39265.
1990	21000.	42.0	10.50	2.451	32.746	2541.	106.	1415.	42441.
1991	28000.	56.0	14.00	3.268	36.014	3388.	141.	1556.	46676.
1992	22000.	44.0	11.00	2.567	38.581	2662.	111.	1667.	50004.
1993	24000.	48.0	12.00	2.801	41.382	2904.	121.	1788.	53634.
1994	30000.	60.0	15.00	3.501	44.883	3630.	151.	1939.	58171.
1995	24000.	48.0	12.00	2.801	47.684	2904.	121.	2060.	61801.
1996	30000.	60.0	15.00	3.501	51.185	3630.	151.	2211.	66339.
1997	30000.	60.0	15.00	3.501	54.686	3630.	151.	2363.	70876.
1998	33000.	66.0	16.50	3.851	58.537	3993.	166.	2529.	75866.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 75 : 25
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb)
   1978-1998 = 2.334 x 10^5 tons @ 80% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Eastern) = 242

(continued)

TABLE B-1d. 1.2-LB $SO_2/10^6$ BTU: 25 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2825.
1980	21101.	42.2	31.65	2.982	5.163	3090.	129.	223.	6666.
1981	15639.	31.3	23.46	2.210	7.373	2290.	95.	318.	9551.
1982	17854.	35.7	26.76	2.523	9.896	2615.	109.	427.	12620.
1983	18079.	36.2	27.12	2.555	12.450	2648.	110.	538.	16130.
1984	16319.	32.6	24.48	2.306	14.757	2390.	100.	637.	19117.
1985	19515.	39.0	29.27	2.758	17.514	2858.	119.	756.	22690.
1986	18000.	36.0	27.00	2.544	20.058	2636.	110.	866.	25966.
1987	17000.	34.0	25.50	2.402	22.460	2490.	104.	970.	29096.
1988	20000.	40.0	30.00	2.826	25.287	2929.	122.	1092.	32759.
1989	19000.	38.0	28.50	2.685	27.972	2783.	116.	1208.	36238.
1990	21000.	42.0	31.50	2.968	30.939	3076.	128.	1336.	40082.
1991	28000.	56.0	42.00	3.957	34.896	4101.	171.	1507.	45209.
1992	22000.	44.0	33.00	3.109	38.005	3222.	134.	1641.	49236.
1993	24000.	48.0	36.00	3.392	41.397	3515.	146.	1788.	53630.
1994	30000.	60.0	45.00	4.239	45.636	4394.	183.	1971.	59122.
1995	24000.	48.0	36.00	3.392	49.028	3515.	146.	2117.	63516.
1996	30000.	60.0	45.00	4.239	53.267	4394.	183.	2300.	69008.
1997	30000.	60.0	45.00	4.239	57.506	4394.	183.	2483.	74501.
1998	33000.	66.0	49.50	4.663	62.170	4833.	201.	2685.	80542.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 75: 25
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - WESTERN COAL
   (0.8% Sulfur, 6% Ash, 8000 Btu/lb)
   = 9.421 x 10^4 tons @ 40% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   = 97.64

(continued)

TABLE B-1d. 1.2-LB $SO_2/10^6$ BTU: 25 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL			WESTERN COAL			NATIONWIDE		
			ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	TOTAL ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.997	389.	11660.	2.181	94.	2825.	11.	483.	14486.
1980	21101.	42.2	11.459	495.	14852.	5.163	223.	6688.	17.	718.	21540.
1981	15639.	31.3	13.284	574.	17217.	7.373	318.	9551.	21.	892.	26769.
1982	17854.	35.7	15.366	664.	19918.	9.896	427.	12820.	25.	1091.	32738.
1983	18079.	36.2	17.478	755.	22652.	12.450	538.	16130.	30.	1293.	38782.
1984	16319.	32.6	19.382	837.	25121.	14.757	637.	19117.	34.	1475.	44238.
1985	19515.	39.0	21.660	936.	28072.	17.514	756.	22690.	39.	1692.	50762.
1986	18000.	36.0	23.760	1026.	30795.	20.058	866.	25986.	44.	1893.	56780.
1987	17000.	34.0	25.744	1112.	33366.	22.460	970.	29098.	48.	2082.	62464.
1988	20000.	40.0	28.078	1213.	36391.	25.287	1092.	32759.	53.	2305.	69150.
1989	19000.	38.0	30.295	1309.	39265.	27.972	1206.	36238.	58.	2517.	75503.
1990	21000.	42.0	32.746	1415.	42441.	30.939	1336.	40082.	64.	2751.	82524.
1991	28000.	56.0	36.014	1556.	46676.	34.896	1507.	45209.	71.	3063.	91885.
1992	22000.	44.0	38.561	1667.	50004.	38.005	1641.	49236.	77.	3308.	99240.
1993	24000.	48.0	41.382	1788.	53634.	41.397	1788.	53630.	83.	3575.	107264.
1994	30000.	60.0	44.883	1939.	58171.	45.636	1971.	59122.	91.	3910.	117294.
1995	24000.	48.0	47.684	2060.	61801.	49.028	2117.	63516.	97.	4177.	125317.
1996	30000.	60.0	51.185	2211.	66339.	53.267	2300.	69008.	104.	4512.	135347.
1997	30000.	60.0	54.686	2363.	70876.	57.506	2483.	74501.	112.	4846.	145377.
1998	33000.	66.0	58.537	2529.	75868.	62.170	2685.	80542.	121.	5214.	156410.

TABLE B-2a. 90-PERCENT SCRUBBING: 55 PERCENT EASTERN COAL

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6018.
1979	15544.	31.1	18.65	4.354	8.997	4514.	188.	389.	11660.
1980	21101.	42.2	23.21	5.761	14.758	5965.	249.	637.	19117.
1981	15639.	31.3	17.20	4.270	19.028	4421.	184.	821.	24644.
1982	17854.	35.7	19.64	4.874	23.902	5047.	210.	1032.	30953.
1983	18079.	36.2	19.89	4.936	28.838	5111.	213.	1245.	37341.
1984	16319.	32.6	17.95	4.455	33.293	4613.	192.	1437.	43108.
1985	19515.	39.0	21.47	5.328	38.621	5517.	230.	1667.	50004.
1986	18000.	36.0	19.80	4.914	43.536	5089.	212.	1879.	56365.
1987	17000.	34.0	18.70	4.641	48.177	4806.	200.	2079.	62373.
1988	20000.	40.0	22.00	5.460	53.637	5654.	236.	2315.	69440.
1989	19000.	38.0	20.90	5.187	58.825	5371.	224.	2538.	76154.
1990	21000.	42.0	23.10	5.733	64.558	5937.	247.	2786.	83575.
1991	28000.	56.0	30.80	7.645	72.203	7916.	330.	3116.	93470.
1992	22000.	44.0	24.20	6.006	78.209	6219.	259.	3375.	101244.
1993	24000.	48.0	26.40	6.552	84.762	6785.	283.	3658.	109725.
1994	30000.	60.0	33.00	8.191	92.952	8481.	353.	4011.	120326.
1995	24000.	48.0	26.40	6.552	99.505	6785.	283.	4294.	128807.
1996	30000.	60.0	33.00	8.191	107.695	8481.	353.	4647.	139409.
1997	30000.	60.0	33.00	8.191	115.886	8481.	353.	5000.	150010.
1998	33000.	66.0	36.30	9.010	124.895	9329.	389.	5389.	161671.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980 - 1998 = 45: 55
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb)
   1978 - 1979 = 2.334 x 10^5 tons @ 80% SCRUBBING
   1980 - 1998 = 2.482 x 10^5 tons @ 90% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Eastern)
   1978 - 1979 = 242
   1980 - 1998 = 257

(continued)

TABLE B-2a. 90-PERCENT SCRUBBING: 55 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2625.
1980	21101.	42.2	18.99	2.271	4.452	2353.	98.	192.	5766.
1981	15639.	31.3	14.08	1.683	6.135	1744.	73.	265.	7946.
1982	17854.	35.7	16.07	1.922	8.057	1991.	83.	348.	10435.
1983	18079.	36.2	16.27	1.946	10.003	2016.	84.	432.	12955.
1984	16319.	32.6	14.69	1.757	11.760	1820.	76.	508.	15230.
1985	19515.	39.0	17.56	2.101	13.860	2176.	91.	598.	17950.
1986	18000.	36.0	16.20	1.938	15.798	2007.	84.	682.	20459.
1987	17000.	34.0	15.30	1.830	17.628	1896.	79.	761.	22826.
1988	20000.	40.0	18.00	2.153	19.781	2230.	93.	854.	25616.
1989	19000.	38.0	17.10	2.045	21.826	2119.	88.	942.	28265.
1990	21000.	42.0	18.90	2.260	24.086	2342.	98.	1040.	31192.
1991	28000.	56.0	25.20	3.014	27.100	3122.	130.	1170.	35095.
1992	22000.	44.0	19.80	2.368	29.468	2453.	102.	1272.	38161.
1993	24000.	48.0	21.60	2.583	32.052	2676.	112.	1384.	41506.
1994	30000.	60.0	27.00	3.229	35.281	3345.	139.	1523.	45606.
1995	24000.	48.0	21.60	2.583	37.864	2676.	112.	1634.	49033.
1996	30000.	60.0	27.00	3.229	41.093	3345.	139.	1774.	53215.
1997	30000.	60.0	27.00	3.229	44.322	3345.	139.	1913.	57397.
1998	33000.	66.0	29.70	3.552	47.875	3680.	153.	2067.	61997.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 45: 55
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - WESTERN COAL
   (0.8% Sulfur, 6% Ash, 8000 Btu/lb)
   1978 - 1979 = 9.421 x 10^4 tons @ 40% SCRUBBING
   1980 - 1998 = 1.196 x 10^5 tons @ 90% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   1978 - 1979 = 97.64
   1980 - 1998 = 123.9

(continued)

TABLE B-2a. 90-PERCENT SCRUBBING: 55 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL: ANNUAL DRY WASTE, MILLION TONS	EASTERN COAL: ANNUAL ACRES	EASTERN COAL: TOTAL ANNUAL ACREAGE REQUIRED	WESTERN COAL: ANNUAL DRY WASTE, MILLION TONS	WESTERN COAL: ANNUAL ACRES	WESTERN COAL: TOTAL ANNUAL ACREAGE REQUIRED	NATIONWIDE: TOTAL ANNUAL DRY WASTE, MILLION TONS	NATIONWIDE: TOTAL ANNUAL ACRES	NATIONWIDE: TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.597	389.	11660.	2.181	94.	2825.	11.	483.	14486.
1980	21101.	42.2	14.738	637.	19117.	4.452	192.	5766.	19.	829.	24883.
1981	15639.	31.3	19.028	821.	24644.	6.135	265.	7946.	25.	1086.	32590.
1982	17854.	35.7	23.902	1032.	30953.	8.057	348.	10435.	32.	1380.	41388.
1983	18079.	36.2	28.838	1245.	37341.	10.003	432.	12955.	39.	1677.	50296.
1984	16319.	32.6	33.293	1437.	43108.	11.760	508.	15230.	45.	1945.	58338.
1985	19515.	39.0	38.621	1667.	50004.	13.860	598.	17950.	52.	2265.	67954.
1986	18000.	36.0	43.536	1879.	56365.	15.798	682.	20459.	59.	2561.	76824.
1987	17000.	34.0	48.177	2079.	62373.	17.628	761.	22828.	66.	2840.	85201.
1988	20000.	40.0	53.637	2315.	69440.	19.761	854.	25616.	73.	3169.	95056.
1989	19000.	38.0	58.825	2538.	76154.	21.826	942.	28265.	81.	3481.	104419.
1990	21000.	42.0	64.558	2786.	83575.	24.086	1040.	31192.	89.	3826.	114767.
1991	28000.	56.0	72.203	3116.	93470.	27.100	1170.	35095.	99.	4285.	128564.
1992	22000.	44.0	78.209	3375.	101244.	29.468	1272.	38161.	106.	4647.	139405.
1993	24000.	48.0	84.762	3658.	109725.	32.052	1384.	41506.	117.	5041.	151232.
1994	30000.	60.0	92.952	4011.	120326.	35.281	1523.	45688.	128.	5534.	166015.
1995	24000.	48.0	99.505	4294.	128807.	37.864	1634.	49033.	137.	5928.	177841.
1996	30000.	60.0	107.695	4647.	139409.	41.093	1774.	53215.	149.	6421.	192624.
1997	30000.	60.0	115.886	5000.	150010.	44.322	1913.	57397.	160.	6914.	207407.
1998	33000.	66.0	124.895	5389.	161671.	47.875	2067.	61997.	173.	7456.	223668.

TABLE B-2b. 90-PERCENT SCRUBBING: 85 PERCENT EASTERN COAL

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6018.
1979	15544.	31.1	18.65	4.354	8.997	4514.	188.	389.	11660.
1980	21101.	42.2	35.87	8.903	17.900	9219.	384.	773.	23184.
1981	15639.	31.3	26.59	6.599	24.499	6833.	285.	1058.	31725.
1982	17854.	35.7	30.35	7.533	32.032	7800.	325.	1383.	41476.
1983	18079.	36.2	30.73	7.628	39.660	7899.	329.	1712.	51349.
1984	16319.	32.6	27.74	6.866	46.546	7130.	297.	2009.	60262.
1985	19515.	39.0	33.18	8.234	54.780	8526.	355.	2364.	70919.
1986	18000.	36.0	30.60	7.595	62.375	7864.	328.	2692.	80750.
1987	17000.	34.0	28.90	7.173	69.548	7427.	309.	3001.	90034.
1988	20000.	40.0	34.00	8.439	77.987	6738.	364.	3365.	100956.
1989	19000.	38.0	32.30	8.017	86.004	8301.	346.	3711.	111333.
1990	21000.	42.0	35.70	8.861	94.864	9175.	382.	4093.	122801.
1991	28000.	56.0	47.60	11.814	106.679	12233.	510.	4603.	138093.
1992	22000.	44.0	37.40	9.283	115.961	9612.	400.	5004.	150108.
1993	24000.	48.0	40.80	10.127	126.088	10486.	437.	5440.	163215.
1994	30000.	60.0	51.00	12.658	138.746	13107.	546.	5987.	179599.
1995	24000.	48.0	40.80	10.127	148.873	10486.	437.	6424.	192706.
1996	30000.	60.0	51.00	12.658	161.531	13107.	546.	6970.	209090.
1997	30000.	60.0	51.00	12.658	174.189	13107.	546.	7516.	225474.
1998	33000.	66.0	56.10	13.924	188.113	14416.	601.	8117.	243496.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980 - 1998 = 15: 85
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb)
   1978 - 1979 = 2.334 x 10^5 tons @ 80% SCRUBBING
   1980 - 1998 = 2.482 x 10^5 tons @ 90% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Eastern)
   1978 - 1979 = 242
   1980 - 1998 = 257

(continued)

TABLE B-2b. 90-PERCENT SCRUBBING: 85 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MW	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2825.
1980	21101.	42.2	6.33	0.757	2.938	784.	33.	127.	3806.
1981	15639.	31.3	4.69	0.561	3.499	581.	24.	151.	4532.
1982	17854.	35.7	5.36	0.641	4.140	664.	28.	179.	5362.
1983	18079.	36.2	5.42	0.649	4.788	672.	28.	207.	6202.
1984	16319.	32.6	4.90	0.586	5.374	607.	25.	232.	6960.
1985	19515.	39.0	5.85	0.700	6.074	725.	30.	262.	7867.
1986	18000.	36.0	5.40	0.646	6.720	669.	28.	290.	8703.
1987	17000.	34.0	5.10	0.610	7.330	632.	26.	316.	9493.
1988	20000.	40.0	6.00	0.718	8.047	743.	31.	347.	10422.
1989	19000.	38.0	5.70	0.682	8.729	706.	29.	377.	11305.
1990	21000.	42.0	6.30	0.753	9.483	781.	33.	409.	12281.
1991	28000.	56.0	8.40	1.005	10.487	1041.	43.	453.	13582.
1992	22000.	44.0	6.60	0.789	11.277	818.	34.	487.	14604.
1993	24000.	48.0	7.20	0.861	12.138	892.	37.	524.	15719.
1994	30000.	60.0	9.00	1.076	13.214	1115.	46.	570.	17113.
1995	24000.	48.0	7.20	0.861	14.075	892.	37.	608.	18228.
1996	30000.	60.0	9.00	1.076	15.152	1115.	46.	654.	19622.
1997	30000.	60.0	9.00	1.076	16.228	1115.	46.	701.	21016.
1998	33000.	66.0	9.90	1.184	17.412	1227.	51.	752.	22549.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 15: 85
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - WESTERN COAL
   (0.8% Sulfur, 6% Ash, 8000 Btu/lb)
   1978 - 1979 = 9.421×10^4 tons @ 40% SCRUBBING
   1980 - 1998 = 1.196×10^5 tons @ 90% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   1978 - 1979 = 97.64
   1980 - 1998 = 123.9

(continued)

TABLE B-2b. 90-PERCENT SCRUBBING: 85 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL			WESTERN COAL			NATIONWIDE		
			ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	TOTAL ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.997	389.	11660.	2.181	94.	2825.	11.	483.	14486.
1980	21101.	42.2	17.900	773.	23184.	2.938	127.	3806.	21.	900.	26990.
1981	15639.	31.3	24.499	1058.	31725.	3.499	151.	4532.	28.	1209.	36257.
1982	17854.	35.7	32.032	1383.	41476.	4.140	179.	5362.	36.	1561.	46838.
1983	18079.	36.2	39.660	1712.	51349.	4.788	207.	6202.	44.	1918.	57551.
1984	16319.	32.6	46.546	2009.	60262.	5.374	232.	6960.	52.	2241.	67222.
1985	19515.	39.0	54.780	2364.	70919.	6.074	262.	7867.	61.	2626.	78786.
1986	18000.	36.0	62.375	2692.	80750.	6.720	290.	8703.	69.	2982.	89453.
1987	17000.	34.0	69.548	3001.	90034.	7.330	316.	9493.	77.	3316.	99527.
1988	20000.	40.0	77.987	3365.	100956.	8.047	347.	10422.	86.	3713.	111378.
1989	19000.	38.0	86.004	3711.	111333.	8.729	377.	11305.	95.	4088.	122638.
1990	21000.	42.0	94.864	4093.	122801.	9.463	409.	12281.	104.	4503.	135082.
1991	28000.	56.0	106.679	4603.	138093.	10.487	453.	13582.	117.	5056.	151675.
1992	22000.	44.0	115.961	5004.	150108.	11.277	487.	14604.	127.	5490.	164712.
1993	24000.	48.0	126.088	5440.	163215.	12.138	524.	15719.	138.	5964.	178934.
1994	30000.	60.0	138.746	5987.	179599.	13.214	570.	17113.	152.	6557.	196712.
1995	24000.	48.0	148.873	6424.	192706.	14.075	606.	18228.	163.	7031.	210934.
1996	30000.	60.0	161.531	6970.	209090.	15.152	654.	19622.	177.	7624.	228711.
1997	30000.	60.0	174.189	7516.	225474.	16.228	701.	21016.	190.	8216.	246489.
1998	33000.	66.0	188.113	8117.	243496.	17.412	752.	22549.	206.	8868.	266045.

TABLE B-2c. 90-PERCENT SCRUBBING: 70 PERCENT EASTERN COAL

			EASTERN COAL						
YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6018.
1979	15544.	31.1	18.65	4.354	8.997	4514.	188.	389.	11660.
1980	21101.	42.2	29.54	7.332	16.329	7592.	316.	705.	21151.
1981	15639.	31.3	21.89	5.434	21.763	5627.	234.	939.	28184.
1982	17854.	35.7	25.00	6.204	27.967	6424.	268.	1207.	36214.
1983	18079.	36.2	25.31	6.282	34.249	6505.	271.	1478.	44345.
1984	16319.	32.6	22.85	5.671	39.920	5872.	245.	1723.	51685.
1985	19515.	39.0	27.32	6.781	46.701	7021.	293.	2015.	60462.
1986	18000.	36.0	25.20	6.255	52.955	6476.	270.	2285.	68557.
1987	17000.	34.0	23.80	5.907	58.863	6117.	255.	2540.	76203.
1988	20000.	40.0	28.00	6.950	65.812	7196.	300.	2840.	85198.
1989	19000.	38.0	26.60	6.602	72.414	6836.	285.	3125.	93744.
1990	21000.	42.0	29.40	7.297	79.711	7556.	315.	3440.	103188.
1991	28000.	56.0	39.20	9.729	89.441	10074.	420.	3859.	115781.
1992	22000.	44.0	30.80	7.645	97.085	7916.	330.	4189.	125676.
1993	24000.	48.0	33.60	8.340	105.425	8635.	360.	4549.	136470.
1994	30000.	60.0	42.00	10.424	115.849	10794.	450.	4999.	149963.
1995	24000.	48.0	33.60	8.340	124.189	8635.	360.	5359.	160757.
1996	30000.	60.0	42.00	10.424	134.613	10794.	450.	5808.	174249.
1997	30000.	60.0	42.00	10.424	145.037	10794.	450.	6258.	187742.
1998	33000.	66.0	46.20	11.467	156.504	11873.	495.	6753.	202563.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980 - 1998 = 30 : 70
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb)
   1978 - 1979 = 2.334 x 10^5 tons @ 80% SCRUBBING
   1980 - 1998 = 2.482 x 10^5 tons @ 90% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Eastern)
   1978 - 1979 = 242
   1980 - 1998 = 257

(continued)

TABLE B-2c. 90-PERCENT SCRUBBING: 70 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MW	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2825.
1980	21101.	42.2	12.66	1.514	3.695	1569.	65.	160.	4786.
1981	15639.	31.3	9.38	1.122	4.817	1163.	48.	208.	6239.
1982	17854.	35.7	10.71	1.281	6.098	1327.	55.	263.	7898.
1983	18079.	36.2	10.85	1.297	7.396	1344.	56.	319.	9578.
1984	16319.	32.6	9.79	1.171	8.567	1213.	51.	370.	11095.
1985	19515.	39.0	11.71	1.400	9.967	1451.	60.	430.	12908.
1986	18000.	36.0	10.80	1.292	11.259	1338.	56.	486.	14581.
1987	17000.	34.0	10.20	1.220	12.479	1264.	53.	539.	16161.
1988	20000.	40.0	12.00	1.435	13.914	1487.	62.	601.	18019.
1989	19000.	38.0	11.40	1.363	15.277	1412.	59.	659.	19785.
1990	21000.	42.0	12.60	1.507	16.784	1561.	65.	725.	21736.
1991	28000.	56.0	16.80	2.009	18.794	2082.	87.	811.	24338.
1992	22000.	44.0	13.20	1.579	20.372	1635.	68.	879.	26382.
1993	24000.	48.0	14.40	1.722	22.095	1784.	74.	954.	28613.
1994	30000.	60.0	18.00	2.153	24.247	2230.	93.	1047.	31400.
1995	24000.	48.0	14.40	1.722	25.970	1784.	74.	1121.	33631.
1996	30000.	60.0	18.00	2.153	28.122	2230.	93.	1214.	36418.
1997	30000.	60.0	18.00	2.153	30.275	2230.	93.	1307.	39206.
1998	33000.	66.0	19.80	2.368	32.643	2453.	102.	1409.	42273.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 - 35: 65
   1979 - 40: 60
   1980-1998 - 30: 70
2. ACRES REQUIRED - ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - WESTERN COAL
   (0.8% Sulfur, 6% Ash, 8000 Btu/lb)
   1978 - 1979 - 9.421 x 10^4 tons @ 40% SCRUBBING
   1980 - 1998 - 1.196 x 10^5 tons @ 90% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   1978 - 1979 - 97.64
   1980 - 1998 - 123.9

(continued)

TABLE B-2c. 90-PERCENT SCRUBBING: 70 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL			WESTERN COAL			NATIONWIDE		
			ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	TOTAL ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.997	389.	11660.	2.181	94.	2825.	11.	483.	14486.
1980	21101.	42.2	16.329	705.	21151.	3.695	160.	4786.	20.	865.	25937.
1981	15639.	31.3	21.763	939.	28184.	4.817	208.	6239.	27.	1147.	34424.
1982	17854.	35.7	27.967	1207.	36214.	6.098	263.	7898.	34.	1470.	44113.
1983	18079.	36.2	34.249	1478.	44345.	7.396	319.	9578.	42.	1797.	53924.
1984	16319.	32.6	39.920	1723.	51665.	8.567	370.	11095.	48.	2093.	62760.
1985	19515.	39.0	46.701	2015.	60462.	9.967	430.	12908.	57.	2446.	73370.
1986	18000.	36.0	52.955	2285.	68557.	11.259	486.	14581.	64.	2771.	83138.
1987	17000.	34.0	58.863	2540.	76203.	12.479	539.	16161.	71.	3079.	92364.
1988	20000.	40.0	65.812	2840.	85198.	13.914	601.	18019.	80.	3441.	103217.
1989	19000.	38.0	72.414	3125.	93744.	15.277	659.	19785.	88.	3784.	113528.
1990	21000.	42.0	79.711	3440.	103188.	16.764	725.	21736.	96.	4164.	124924.
1991	28000.	56.0	89.441	3859.	115781.	18.794	811.	24338.	108.	4671.	140120.
1992	22000.	44.0	97.085	4189.	125676.	20.372	879.	26382.	117.	5069.	152058.
1993	24000.	48.0	105.425	4549.	136470.	22.095	954.	28613.	128.	5503.	165083.
1994	30000.	60.0	115.849	4999.	149963.	24.247	1047.	31400.	140.	6045.	181363.
1995	24000.	48.0	124.189	5359.	160757.	25.970	1121.	33631.	150.	6480.	194387.
1996	30000.	60.0	134.613	5808.	174249.	28.122	1214.	36418.	163.	7022.	210667.
1997	30000.	60.0	145.037	6258.	187742.	30.275	1307.	39206.	175.	7565.	226948.
1998	33000.	66.0	156.504	6753.	202583.	32.643	1409.	42273.	189.	8162.	244856.

TABLE B-2d. 90-PERCENT SCRUBBING: 25 PERCENT EASTERN COAL

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6018.
1979	15544.	31.1	18.65	4.354	8.997	4514.	188.	389.	11660.
1980	21101.	42.2	10.55	2.619	11.615	2711.	113.	502.	15050.
1981	15639.	31.3	7.82	1.941	13.556	2010.	84.	585.	17562.
1982	17854.	35.7	8.93	2.216	15.772	2294.	96.	681.	20430.
1983	18079.	36.2	9.04	2.244	18.016	2323.	97.	778.	23334.
1984	16319.	32.6	8.16	2.025	20.041	2097.	87.	865.	25955.
1985	19515.	39.0	9.76	2.422	22.462	2508.	104.	970.	29090.
1986	18000.	36.0	9.00	2.234	24.696	2313.	96.	1066.	31981.
1987	17000.	34.0	8.50	2.110	26.806	2185.	91.	1157.	34711.
1988	20000.	40.0	10.00	2.482	29.288	2570.	107.	1264.	37924.
1989	19000.	38.0	9.50	2.358	31.646	2442.	102.	1366.	40976.
1990	21000.	42.0	10.50	2.606	34.252	2699.	112.	1478.	44349.
1991	28000.	56.0	14.00	3.475	37.727	3598.	150.	1628.	48847.
1992	22000.	44.0	11.00	2.730	40.457	2827.	118.	1746.	52380.
1993	24000.	48.0	12.00	2.978	43.435	3084.	129.	1875.	56235.
1994	30000.	60.0	15.00	3.723	47.158	3855.	161.	2035.	61054.
1995	24000.	48.0	12.00	2.978	50.137	3084.	129.	2164.	64909.
1996	30000.	60.0	15.00	3.723	53.860	3855.	161.	2324.	69728.
1997	30000.	60.0	15.00	3.723	57.583	3855.	161.	2485.	74547.
1998	33000.	66.0	16.50	4.095	61.678	4241.	177.	2662.	79847.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980 - 1998 = 75 : 25
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb)
   1978 - 1979 = 2.334 x 10^5 tons @ 80% SCRUBBING
   1980 - 1998 = 2.482 x 10^5 tons @ 90% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Eastern)
   1978 - 1979 = 242
   1980 - 1998 = 257

(continued)

TABLE B-2d. 90-PERCENT SCRUBBING: 25 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2825.
1980	21101.	42.2	31.65	3.786	5.966	3922.	163.	256.	7727.
1981	15639.	31.3	23.46	2.806	8.772	2907.	121.	379.	11360.
1982	17854.	35.7	26.78	3.203	11.975	3318.	138.	517.	15508.
1983	18079.	36.2	27.12	3.243	15.218	3360.	140.	657.	19708.
1984	16319.	32.6	24.48	2.928	18.146	3033.	126.	763.	23499.
1985	19515.	39.0	29.27	3.501	21.647	3627.	151.	934.	28033.
1986	18000.	36.0	27.00	3.229	24.876	3345.	139.	1074.	32215.
1987	17000.	34.0	25.50	3.050	27.926	3159.	132.	1205.	36164.
1988	20000.	40.0	30.00	3.588	31.514	3717.	155.	1360.	40610.
1989	19000.	38.0	28.50	3.409	34.922	3531.	147.	1507.	45224.
1990	21000.	42.0	31.50	3.767	38.690	3903.	163.	1670.	50103.
1991	28000.	56.0	42.00	5.023	43.713	5204.	217.	1887.	56607.
1992	22000.	44.0	33.00	3.947	47.660	4089.	170.	2057.	61716.
1993	24000.	48.0	36.00	4.306	51.965	4460.	186.	2243.	67294.
1994	30000.	60.0	45.00	5.382	57.347	5575.	232.	2475.	74263.
1995	24000.	48.0	36.00	4.306	61.653	4460.	186.	2661.	79839.
1996	30000.	60.0	45.00	5.382	67.035	5575.	232.	2894.	86806.
1997	30000.	60.0	45.00	5.382	72.417	5575.	232.	3126.	93778.
1998	33000.	66.0	49.50	5.920	78.337	6133.	256.	3381.	101444.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 75: 25
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL DRY WASTE/PLANT - WESTERN COAL
   (0.8% Sulfur, 6% Ash, 8000 Btu/lb)
   1978 - 1979 = 9.421 x 10^4 tons @ 40% SCRUBBING
   1980 - 1998 = 1.196 x 10^5 tons @ 90% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   1978 - 1979 = 97.64
   1980 - 1998 = 123.9

(continued)

TABLE B-2d. 90-PERCENT SCRUBBING: 25 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL			WESTERN COAL			NATIONWIDE		
			ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	TOTAL ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.997	389.	11660.	2.181	94.	2825.	11.	483.	14486.
1980	21101.	42.2	11.615	502.	15050.	5.966	258.	7727.	18.	759.	22777.
1981	15639.	31.3	13.556	585.	17562.	8.772	379.	11360.	22.	964.	28922.
1982	17854.	35.7	15.772	681.	20430.	11.975	517.	15506.	28.	1198.	35936.
1983	18079.	36.2	18.016	778.	23334.	15.218	657.	19708.	33.	1435.	43042.
1984	16319.	32.6	20.041	865.	25955.	18.146	783.	23499.	38.	1648.	49454.
1985	19515.	39.0	22.462	970.	29090.	21.647	934.	28033.	44.	1904.	57122.
1986	18000.	36.0	24.696	1066.	31981.	24.876	1074.	32215.	50.	2140.	64195.
1987	17000.	34.0	26.806	1157.	34711.	27.926	1205.	36164.	55.	2363.	70875.
1988	20000.	40.0	29.288	1264.	37924.	31.514	1360.	40810.	61.	2624.	78734.
1989	19000.	38.0	31.646	1366.	40976.	34.922	1507.	45224.	67.	2873.	86200.
1990	21000.	42.0	34.252	1478.	44349.	38.690	1670.	50103.	73.	3148.	94452.
1991	28000.	56.0	37.727	1628.	48847.	43.713	1887.	56607.	81.	3515.	105454.
1992	22000.	44.0	40.457	1746.	52380.	47.660	2057.	61718.	88.	3803.	114099.
1993	24000.	48.0	43.435	1875.	56235.	51.965	2243.	67294.	95.	4118.	123529.
1994	30000.	60.0	47.158	2035.	61054.	57.347	2475.	74263.	105.	4511.	135317.
1995	24000.	48.0	50.137	2164.	64909.	61.653	2661.	79839.	112.	4825.	144748.
1996	30000.	60.0	53.860	2324.	69728.	67.035	2894.	86806.	121.	5218.	156536.
1997	30000.	60.0	57.583	2485.	74547.	72.417	3126.	93778.	130.	5611.	168324.
1998	33000.	66.0	61.678	2662.	79847.	78.337	3381.	101444.	140.	6043.	181291.

TABLE B-3a. 0.5-LB $SO_2/10^6$ BTU: 55 PERCENT EASTERN COAL

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6018.
1979	15544.	31.1	18.65	4.354	8.997	4514.	188.	389.	11660.
1980	21101.	42.2	23.21	3.196	12.193	3312.	138.	527.	15801.
1981	15639.	31.3	17.20	2.369	14.562	2455.	102.	629.	18869.
1982	17854.	35.7	19.64	2.704	17.266	2803.	117.	746.	22373.
1983	18079.	36.2	19.89	2.738	20.005	2838.	118.	864.	25920.
1984	16319.	32.6	17.95	2.472	22.476	2562.	107.	971.	29122.
1985	19515.	39.0	21.47	2.956	25.432	3063.	128.	1098.	32951.
1986	18000.	36.0	19.80	2.726	28.159	2825.	118.	1216.	36463.
1987	17000.	34.0	18.70	2.575	30.734	2668.	111.	1327.	39818.
1988	20000.	40.0	22.00	3.029	33.763	3139.	131.	1458.	43743.
1989	19000.	38.0	20.90	2.878	36.641	2982.	124.	1582.	47471.
1990	21000.	42.0	23.10	3.181	39.822	3296.	137.	1720.	51591.
1991	28000.	56.0	30.80	4.241	44.063	4395.	183.	1903.	57085.
1992	22000.	44.0	24.20	3.332	47.395	3453.	144.	2047.	61402.
1993	24000.	48.0	26.40	3.635	51.031	3767.	157.	2204.	66111.
1994	30000.	60.0	33.00	4.544	55.575	4709.	196.	2400.	71996.
1995	24000.	48.0	26.40	3.635	59.210	3767.	157.	2557.	76707.
1996	30000.	60.0	33.00	4.544	63.754	4709.	196.	2753.	82593.
1997	30000.	60.0	33.00	4.544	68.298	4709.	196.	2949.	88480.
1998	33000.	66.0	36.30	4.999	73.297	5180.	216.	3165.	94955.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 - 35: 65
   1979 - 40: 60
   1980-1998 - 45: 55
2. ACRES REQUIRED - ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL ACRE-FEET/PLANT (Eastern)
   1978-1979 - 242
   1980-1998 - 142.7
4. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   1978-1979 - 2.334 x 10^5 tons @ 80% SCRUBBING
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb; No Wash)
   1980-1998 - 1.377 x 10^5 tons @ 85% SCRUBBING
   (3.5% Sulfur, 14% Ash, 13,200 Btu/lb;
   40% of Sulfur Removed By Wash)

(continued)

TABLE B-3a. 0.5-LB $SO_2/10^6$ BTU: 55 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL WITH 40% WASH						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	0.0	0.0	0.	0.	0.	0.
1979	15544.	31.1	18.65	0.0	0.0	0.	0.	0.	0.
1980	21101.	42.2	23.21	0.949	0.949	641.	27.	27.	801.
1981	15639.	31.3	17.20	0.703	1.653	475.	20.	46.	1394.
1982	17854.	35.7	19.64	0.803	2.456	542.	23.	69.	2072.
1983	18079.	36.2	19.89	0.813	3.269	549.	23.	92.	2758.
1984	16319.	32.6	17.95	0.734	4.003	495.	21.	113.	3377.
1985	19515.	39.0	21.47	0.878	4.881	592.	25.	137.	4116.
1986	18000.	36.0	19.80	0.810	5.690	546.	23.	160.	4801.
1987	17000.	34.0	18.70	0.765	6.455	516.	22.	182.	5446.
1988	20000.	40.0	22.00	0.900	7.354	607.	25.	207.	6205.
1989	19000.	38.0	20.90	0.855	8.209	577.	24.	231.	6926.
1990	21000.	42.0	23.10	0.945	9.154	638.	27.	257.	7723.
1991	28000.	56.0	30.80	1.259	10.413	850.	35.	293.	8766.
1992	22000.	44.0	24.20	0.990	11.402	668.	28.	321.	9621.
1993	24000.	48.0	26.40	1.079	12.482	729.	30.	351.	10531.
1994	30000.	60.0	33.00	1.349	13.831	911.	38.	389.	11670.
1995	24000.	48.0	26.40	1.079	14.911	729.	30.	419.	12581.
1996	30000.	60.0	33.00	1.349	16.260	911.	38.	457.	13719.
1997	30000.	60.0	33.00	1.349	17.610	911.	38.	495.	14858.
1998	33000.	66.0	36.30	1.484	19.094	1002.	42.	537.	16110.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 45: 55
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. 40% COAL WASH:
   ANNUAL DRY WASTE = 4.089 x 10^4 tons
   ACRE-FEET = 27.6

(continued)

TABLE B-3a. 0.5-LB $SO_2/10^6$ BTU: 55 PERCENT EASTERN COAL (Continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2825.
1980	21101.	42.2	18.99	2.127	4.308	2203.	92.	186.	5579.
1981	15639.	31.3	14.08	1.576	5.884	1633.	68.	254.	7620.
1982	17854.	35.7	16.07	1.800	7.684	1864.	78.	332.	9950.
1983	18079.	36.2	16.27	1.822	9.506	1887.	79.	410.	12309.
1984	16319.	32.6	14.69	1.645	11.151	1704.	71.	481.	14439.
1985	19515.	39.0	17.56	1.967	13.118	2037.	85.	566.	16985.
1986	18000.	36.0	16.20	1.814	14.933	1879.	78.	644.	19334.
1987	17000.	34.0	15.30	1.714	16.646	1775.	74.	718.	21553.
1988	20000.	40.0	18.00	2.016	18.662	2088.	87.	805.	24163.
1989	19000.	38.0	17.10	1.915	20.577	1984.	83.	888.	26642.
1990	21000.	42.0	18.90	2.117	22.694	2192.	91.	979.	29383.
1991	28000.	56.0	25.20	2.822	25.517	2923.	122.	1101.	33037.
1992	22000.	44.0	19.80	2.218	27.734	2297.	96.	1197.	35908.
1993	24000.	48.0	21.60	2.419	30.153	2506.	104.	1301.	39040.
1994	30000.	60.0	27.00	3.024	33.177	3132.	131.	1432.	42955.
1995	24000.	48.0	21.60	2.419	35.597	2506.	104.	1536.	46087.
1996	30000.	60.0	27.00	3.024	38.620	3132.	131.	1667.	50002.
1997	30000.	60.0	27.00	3.024	41.644	3132.	131.	1797.	53917.
1998	33000.	66.0	29.70	3.326	44.971	3445.	144.	1941.	58224.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 45: 55
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. (0.8% Sulfur, 6% Ash, 8000 Btu/lb) WESTERN COAL
   1978-1979 = 9.421 x 10^4 tons @ 40% SCRUBBING
   1980-1998 = 1.120 x 10^5 tons @ 75% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   1978-1979 = 97.64
   1980-1998 = 116.0

(continued)

TABLE B-3a. 0.5-LB $SO_2/10^6$ BTU: 55 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL			WESTERN COAL			NATIONWIDE		
			ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	TOTAL ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.997	389.	11660.	2.181	94.	2825.	11.	483.	14486.
1980	21101.	42.2	12.193	527.	15801.	4.308	186.	5579.	17.	713.	21380.
1981	15639.	31.3	14.562	629.	18869.	5.884	254.	7620.	20.	883.	26489.
1982	17854.	35.7	17.266	746.	22373.	7.684	332.	9950.	25.	1077.	32322.
1983	18079.	36.2	20.005	864.	25920.	9.506	410.	12309.	30.	1274.	38229.
1984	16319.	32.6	22.476	971.	29122.	11.151	461.	14439.	34.	1452.	43561.
1985	19515.	39.0	25.432	1098.	32951.	13.118	566.	16985.	39.	1665.	49936.
1986	18000.	36.0	28.159	1216.	36483.	14.933	644.	19334.	43.	1861.	55817.
1987	17000.	34.0	30.734	1327.	39818.	16.646	718.	21553.	47.	2046.	61371.
1988	20000.	40.0	33.763	1458.	43743.	18.662	805.	24163.	52.	2264.	67906.
1989	19000.	38.0	36.641	1582.	47471.	20.577	888.	26642.	57.	2470.	74113.
1990	21000.	42.0	39.822	1720.	51591.	22.694	979.	29363.	63.	2699.	80974.
1991	28000.	56.0	44.063	1903.	57085.	25.517	1101.	33037.	70.	3004.	90122.
1992	22000.	44.0	47.395	2047.	61402.	27.734	1197.	35906.	75.	3244.	97310.
1993	24000.	48.0	51.031	2204.	66111.	30.153	1301.	39040.	81.	3505.	105151.
1994	30000.	60.0	55.575	2400.	71998.	33.177	1432.	42955.	89.	3832.	114953.
1995	24000.	48.0	59.210	2557.	76707.	35.597	1536.	46087.	95.	4093.	122794.
1996	30000.	60.0	63.754	2753.	82593.	38.620	1667.	50002.	102.	4420.	132595.
1997	30000.	60.0	68.298	2949.	88480.	41.644	1797.	53917.	110.	4747.	142397.
1998	33000.	66.0	73.297	3165.	94955.	44.971	1941.	58224.	118.	5106.	153178.

TABLE B-3b. 0.5-LB $SO_2/10^6$ BTU: 85 PERCENT EASTERN COAL

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6018.
1979	15544.	31.1	18.65	4.354	8.997	4514.	188.	389.	11660.
1980	21101.	42.2	35.87	4.940	13.936	5119.	213.	602.	18059.
1981	15639.	31.3	26.59	3.661	17.597	3794.	158.	760.	22801.
1982	17854.	35.7	30.35	4.179	21.777	4331.	180.	941.	28216.
1983	18079.	36.2	30.73	4.232	26.009	4386.	183.	1123.	33698.
1984	16319.	32.6	27.74	3.820	29.829	3959.	165.	1288.	38646.
1985	19515.	39.0	33.18	4.568	34.397	4734.	197.	1485.	44564.
1986	18000.	36.0	30.60	4.214	38.611	4367.	182.	1667.	50022.
1987	17000.	34.0	28.90	3.980	42.590	4124.	172.	1839.	55177.
1988	20000.	40.0	34.00	4.682	47.272	4852.	202.	2041.	61242.
1989	19000.	38.0	32.30	4.448	51.720	4609.	192.	2233.	67004.
1990	21000.	42.0	35.70	4.916	56.636	5094.	212.	2446.	73372.
1991	28000.	56.0	47.60	6.555	63.190	6793.	283.	2729.	81863.
1992	22000.	44.0	37.40	5.150	68.340	5337.	222.	2951.	88534.
1993	24000.	48.0	40.80	5.618	73.958	5822.	243.	3194.	95812.
1994	30000.	60.0	51.00	7.023	80.981	7278.	303.	3497.	104909.
1995	24000.	48.0	40.80	5.618	86.599	5822.	243.	3740.	112186.
1996	30000.	60.0	51.00	7.023	93.622	7278.	303.	4043.	121264.
1997	30000.	60.0	51.00	7.023	100.644	7278.	303.	4346.	130381.
1998	33000.	66.0	56.10	7.725	108.369	8005.	334.	4680.	140388.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 15: 85
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL ACRE-FEET/PLANT (Eastern)
   1978-1979 = 242
   1980-1998 = 142.7
4. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   1978-1979 = 2.334×10^5 tons @ 80% SCRUBBING
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb; No Wash)
   1980-1998 = 1.377×10^5 tons @ 85% SCRUBBING
   (3.5% Sulfur, 14% Ash, 13,200 Btu/lb;
   40% of Sulfur Removed By Wash)

(continued)

TABLE B-3b. 0.5-LB $SO_2/10^6$ BTU: 85 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL WITH 40% WASH						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	0.0	0.0	0.	0.	0.	0.
1979	15544.	31.1	18.65	0.0	0.0	0.	0.	0.	0.
1980	21101.	42.2	35.87	1.467	1.467	990.	41.	41.	1238.
1981	15639.	31.3	26.59	1.087	2.554	734.	31.	72.	2155.
1982	17854.	35.7	30.35	1.241	3.795	838.	35.	107.	3202.
1983	18079.	36.2	30.73	1.257	5.052	848.	35.	142.	4262.
1984	16319.	32.6	27.74	1.134	6.186	766.	32.	174.	5219.
1985	19515.	39.0	33.18	1.357	7.543	916.	38.	212.	6364.
1986	18000.	36.0	30.60	1.251	8.794	845.	35.	247.	7420.
1987	17000.	34.0	28.90	1.182	9.976	798.	33.	281.	8417.
1988	20000.	40.0	34.00	1.390	11.366	938.	39.	320.	9590.
1989	19000.	38.0	32.30	1.321	12.687	891.	37.	357.	10704.
1990	21000.	42.0	35.70	1.460	14.146	985.	41.	398.	11938.
1991	28000.	56.0	47.60	1.946	16.093	1314.	55.	453.	13578.
1992	22000.	44.0	37.40	1.529	17.622	1032.	43.	496.	14868.
1993	24000.	48.0	40.80	1.668	19.290	1126.	47.	543.	16276.
1994	30000.	60.0	51.00	2.085	21.376	1408.	59.	601.	18035.
1995	24000.	48.0	40.80	1.668	23.044	1126.	47.	648.	19443.
1996	30000.	60.0	51.00	2.085	25.129	1408.	59.	707.	21203.
1997	30000.	60.0	51.00	2.085	27.215	1408.	59.	765.	22962.
1998	33000.	66.0	56.10	2.294	29.509	1548.	65.	830.	24897.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 - 35: 65
   1979 - 40: 60
   1980-1998 - 15: 85
2. ACRES REQUIRED - ACRE-FEET x $\frac{1.25}{30}$
3. 40% COAL WASH:
   ANNUAL DRY WASTE - 4.089 x 10^4 tons
   ACRE-FEET - 27.6

(continued)

TABLE B-3b. 0.5-LB $SO_2/10^6$ BTU: 85 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2825.
1980	21101.	42.2	6.33	0.709	2.890	734.	31.	125.	3743.
1981	15639.	31.3	4.69	0.525	3.415	544.	23.	147.	4423.
1982	17854.	35.7	5.36	0.600	4.015	621.	26.	173.	5200.
1983	18079.	36.2	5.42	0.607	4.623	629.	26.	200.	5986.
1984	16319.	32.6	4.90	0.548	5.171	568.	24.	223.	6696.
1985	19515.	39.0	5.85	0.656	5.827	679.	28.	252.	7545.
1986	18000.	36.0	5.40	0.605	6.431	626.	26.	278.	8328.
1987	17000.	34.0	5.10	0.571	7.003	592.	25.	302.	9068.
1988	20000.	40.0	6.00	0.672	7.675	696.	29.	331.	9938.
1989	19000.	38.0	5.70	0.638	8.313	661.	28.	359.	10764.
1990	21000.	42.0	6.30	0.706	9.019	731.	30.	389.	11678.
1991	28000.	56.0	8.40	0.941	9.959	974.	41.	430.	12896.
1992	22000.	44.0	6.60	0.739	10.699	766.	32.	462.	13853.
1993	24000.	48.0	7.20	0.806	11.505	835.	35.	497.	14697.
1994	30000.	60.0	9.00	1.008	12.513	1044.	44.	540.	16202.
1995	24000.	48.0	7.20	0.806	13.319	835.	35.	575.	17246.
1996	30000.	60.0	9.00	1.008	14.327	1044.	44.	618.	18551.
1997	30000.	60.0	9.00	1.008	15.335	1044.	44.	662.	19856.
1998	33000.	66.0	9.90	1.109	16.444	1148.	48.	710.	21291.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 15: 85
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. (0.8% Sulfur, 6% Ash, 8000 Btu/lb) WESTERN COAL
   1978-1979 = 9.421 x 10^4 tons @ 40% SCRUBBING
   1980-1998 = 1.120 x 10^5 tons @ 75% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   1978-1979 = 97.64
   1980-1998 = 116.0

(continued)

TABLE B-3b. 0.5-LB $SO_2/10^6$ BTU: 85 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL			WESTERN COAL			NATIONWIDE		
			ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	TOTAL ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.997	389.	11660.	2.181	94.	2825.	11.	483.	14486.
1980	21101.	42.2	13.936	602.	18059.	2.890	125.	3743.	17.	727.	21802.
1981	15639.	31.3	17.597	760.	22801.	3.415	147.	4423.	21.	907.	27225.
1982	17854.	35.7	21.777	941.	28216.	4.015	173.	5200.	26.	1114.	33416.
1983	18079.	36.2	26.009	1123.	33698.	4.623	200.	5986.	31.	1323.	39684.
1984	16319.	32.6	29.829	1288.	38646.	5.171	223.	6696.	35.	1511.	45343.
1985	19515.	39.0	34.397	1485.	44564.	5.827	252.	7545.	40.	1737.	52109.
1986	18000.	36.0	38.611	1667.	50022.	6.431	278.	8326.	45.	1945.	58351.
1987	17000.	34.0	42.590	1839.	55177.	7.003	302.	9068.	50.	2142.	64245.
1988	20000.	40.0	47.272	2041.	61242.	7.675	331.	9938.	55.	2373.	71180.
1989	19000.	38.0	51.720	2233.	67004.	8.313	359.	10764.	60.	2592.	77768.
1990	21000.	42.0	56.636	2446.	73372.	9.019	389.	11678.	66.	2835.	85050.
1991	28000.	56.0	63.190	2729.	81863.	9.959	430.	12896.	73.	3159.	94758.
1992	22000.	44.0	68.340	2951.	88534.	10.699	462.	13853.	79.	3413.	102387.
1993	24000.	48.0	73.958	3194.	95812.	11.505	497.	14897.	85.	3690.	110709.
1994	30000.	60.0	80.981	3497.	104909.	12.513	540.	16202.	93.	4037.	121110.
1995	24000.	48.0	86.599	3740.	112186.	13.319	575.	17246.	100.	4314.	129432.
1996	30000.	60.0	93.622	4043.	121284.	14.327	618.	18551.	108.	4661.	139834.
1997	30000.	60.0	100.644	4346.	130381.	15.335	662.	19856.	116.	5008.	150237.
1998	33000.	66.0	108.369	4680.	140388.	16.444	710.	21291.	125.	5389.	161679.

TABLE B-3c. 0.5-LB $SO_2/10^6$ BTU: 70 PERCENT EASTERN COAL

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6016.
1979	15544.	31.1	18.65	4.354	6.997	4514.	188.	389.	11660.
1980	21101.	42.2	29.54	4.068	13.065	4216.	176.	564.	16930.
1981	15639.	31.3	21.89	3.015	16.080	3124.	130.	695.	20635.
1982	17854.	35.7	25.00	3.442	19.521	3567.	149.	843.	25294.
1983	18079.	36.2	25.31	3.485	23.007	3612.	150.	994.	29809.
1984	16319.	32.6	22.85	3.146	26.153	3260.	136.	1129.	33884.
1985	19515.	39.0	27.32	3.762	29.915	3899.	162.	1292.	38756.
1986	18000.	36.0	25.20	3.470	33.385	3596.	150.	1442.	43253.
1987	17000.	34.0	23.80	3.277	36.662	3396.	142.	1583.	47498.
1988	20000.	40.0	28.00	3.856	40.518	3996.	166.	1750.	52493.
1989	19000.	38.0	26.60	3.663	44.180	3796.	158.	1908.	57237.
1990	21000.	42.0	29.40	4.048	48.229	4195.	175.	2083.	62482.
1991	28000.	56.0	39.20	5.398	53.627	5594.	233.	2316.	69474.
1992	22000.	44.0	30.80	4.241	57.868	4395.	183.	2499.	74968.
1993	24000.	48.0	33.60	4.627	62.494	4795.	200.	2699.	80961.
1994	30000.	60.0	42.00	5.783	68.278	5993.	250.	2948.	88453.
1995	24000.	48.0	33.60	4.627	72.905	4795.	200.	3148.	94447.
1996	30000.	60.0	42.00	5.783	78.688	5993.	250.	3396.	101938.
1997	30000.	60.0	42.00	5.783	84.471	5993.	250.	3646.	109430.
1998	33000.	66.0	46.20	6.362	90.833	6593.	275.	3922.	117671.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 - 35: 65
   1979 - 40: 60
   1980-1998 - 30: 70
2. ACRES REQUIRED - ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL ACRE-FEET/PLANT (Eastern)
   1978-1979 - 242
   1980-1998 - 142.7
4. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   1978-1979 - 2.334 x 10^5 tons @ 80% SCRUBBING
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb; No Wash)
   1980-1998 - 1.377 x 10^5 tons @ 85% SCRUBBING
   (3.5% Sulfur, 14% Ash, 13,200 Btu/lb;
   40% of Sulfur Removed By Wash)

(continued)

TABLE B-3c. 0.5-LB $SO_2/10^6$ BTU: 70 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL WITH 40% WASH						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	0.0	0.0	0.	0.	0.	0.
1979	15544.	31.1	18.65	0.0	0.0	0.	0.	0.	0.
1980	21101.	42.2	29.54	1.208	1.208	815.	34.	34.	1019.
1981	15639.	31.3	21.89	0.895	2.103	604.	25.	59.	1775.
1982	17854.	35.7	25.00	1.022	3.125	690.	29.	88.	2637.
1983	18079.	36.2	25.31	1.035	4.160	699.	29.	117.	3510.
1984	16319.	32.6	22.85	0.934	5.094	631.	26.	143.	4298.
1985	19515.	39.0	27.32	1.117	6.212	754.	31.	175.	5241.
1986	18000.	36.0	25.20	1.030	7.242	696.	29.	204.	6110.
1987	17000.	34.0	23.80	0.973	8.215	657.	27.	231.	6931.
1988	20000.	40.0	28.00	1.145	9.360	773.	32.	263.	7897.
1989	19000.	38.0	26.60	1.088	10.448	734.	31.	294.	8815.
1990	21000.	42.0	29.40	1.202	11.650	811.	34.	328.	9829.
1991	28000.	56.0	39.20	1.603	13.253	1082.	45.	373.	11182.
1992	22000.	44.0	30.80	1.259	14.512	850.	35.	408.	12244.
1993	24000.	48.0	33.60	1.374	15.886	927.	39.	447.	13404.
1994	30000.	60.0	42.00	1.717	17.604	1159.	48.	495.	14853.
1995	24000.	48.0	33.60	1.374	18.977	927.	39.	534.	16012.
1996	30000.	60.0	42.00	1.717	20.695	1159.	45.	582.	17461.
1997	30000.	60.0	42.00	1.717	22.412	1159.	48.	630.	18910.
1998	33000.	66.0	46.20	1.889	24.301	1275.	53.	683.	20504.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 30: 70
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. 40% COAL WASH:
   ANNUAL DRY WASTE = 4.089 x 10^4 tons
   ACRE-FEET = 27.6

(continued)

TABLE B-3c. 0.5-LB $SO_2/10^6$ BTU: 70 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MW	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2825.
1980	21101.	42.2	12.66	1.418	3.599	1469.	61.	155.	4661.
1981	15639.	31.3	9.38	1.051	4.650	1088.	45.	201.	6022.
1982	17854.	35.7	10.71	1.200	5.849	1243.	52.	252.	7575.
1983	18079.	36.2	10.85	1.215	7.064	1258.	52.	305.	9148.
1984	16319.	32.6	9.79	1.097	8.161	1136.	47.	352.	10568.
1985	19515.	39.0	11.71	1.311	9.472	1358.	57.	409.	12265.
1986	18000.	36.0	10.80	1.210	10.682	1253.	52.	461.	13831.
1987	17000.	34.0	10.20	1.142	11.824	1183.	49.	510.	15310.
1988	20000.	40.0	12.00	1.344	13.168	1392.	58.	568.	17050.
1989	19000.	38.0	11.40	1.277	14.445	1322.	55.	623.	18703.
1990	21000.	42.0	12.60	1.411	15.856	1462.	61.	684.	20530.
1991	28000.	56.0	16.80	1.882	17.738	1949.	81.	766.	22966.
1992	22000.	44.0	13.20	1.478	19.216	1531.	64.	829.	24660.
1993	24000.	48.0	14.40	1.613	20.829	1670.	70.	899.	26966.
1994	30000.	60.0	18.00	2.016	22.845	2088.	87.	986.	29578.
1995	24000.	48.0	14.40	1.613	24.458	1670.	70.	1056.	31666.
1996	30000.	60.0	18.00	2.016	26.474	2088.	87.	1143.	34276.
1997	30000.	60.0	18.00	2.016	28.490	2088.	87.	1230.	36887.
1998	33000.	66.0	19.80	2.218	30.708	2297.	96.	1325.	39758.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35:65
   1979 = 40:60
   1980-1998 = 30:70
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. (0.8% Sulfur, 6% Ash, 8000 Btu/lb) WESTERN COAL
   1978-1979 = 9.421×10^4 tons @ 40% SCRUBBING
   1980-1998 = 1.120×10^5 tons @ 75% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   1978-1979 = 97.64
   1980-1998 = 116.0

(continued)

TABLE B-3c. 0.5-LB $SO_2/10^6$ BTU: 70 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL			WESTERN COAL			NATIONWIDE		
			ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	TOTAL ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.997	389.	11660.	2.181	94.	2825.	11.	483.	14486.
1980	21101.	42.2	13.065	564.	16930.	3.599	155.	4661.	17.	720.	21591.
1981	15639.	31.3	16.080	695.	20835.	4.650	201.	6022.	21.	895.	26857.
1982	17854.	35.7	19.521	843.	25294.	5.849	252.	7575.	25.	1096.	32869.
1983	18079.	36.2	23.007	994.	29809.	7.064	305.	9148.	30.	1299.	38957.
1984	16319.	32.6	26.153	1129.	33884.	8.161	352.	10568.	34.	1482.	44452.
1985	19515.	39.0	29.915	1292.	38758.	9.472	409.	12265.	39.	1701.	51023.
1986	18000.	36.0	33.385	1442.	43253.	10.682	461.	13831.	44.	1903.	57084.
1987	17000.	34.0	36.662	1583.	47498.	11.824	510.	15310.	48.	2094.	62808.
1988	20000.	40.0	40.518	1750.	52493.	13.166	568.	17050.	54.	2318.	69543.
1989	19000.	38.0	44.180	1908.	57237.	14.445	623.	18703.	59.	2531.	75941.
1990	21000.	42.0	48.229	2083.	62482.	15.856	684.	20530.	64.	2767.	83012.
1991	28000.	56.0	53.627	2316.	69474.	17.736	766.	22966.	71.	3081.	92440.
1992	22000.	44.0	57.868	2499.	74968.	19.216	829.	24880.	77.	3328.	99848.
1993	24000.	48.0	62.494	2699.	80961.	20.829	899.	26968.	83.	3598.	107930.
1994	30000.	60.0	68.278	2948.	88453.	22.845	986.	29578.	91.	3934.	118032.
1995	24000.	48.0	72.905	3148.	94447.	24.458	1056.	31666.	97.	4204.	126113.
1996	30000.	60.0	78.688	3398.	101938.	26.474	1143.	34276.	105.	4540.	136215.
1997	30000.	60.0	84.471	3648.	109430.	28.490	1230.	36887.	113.	4877.	146317.
1998	33000.	66.0	90.833	3922.	117671.	30.708	1325.	39758.	122.	5248.	157429.

TABLE B-3d. 0.5-LB $SO_2/10^6$ BTU: 25 PERCENT EASTERN COAL

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	4.643	4.643	4814.	201.	201.	6018.
1979	15544.	31.1	18.65	4.354	8.997	4514.	188.	389.	11660.
1980	21101.	42.2	10.55	1.453	10.450	1506.	63.	451.	13542.
1981	15639.	31.3	7.82	1.077	11.526	1116.	46.	498.	14937.
1982	17854.	35.7	8.93	1.229	12.756	1274.	53.	551.	16530.
1983	18079.	36.2	9.04	1.245	14.000	1290.	54.	605.	18142.
1984	16319.	32.6	8.16	1.124	15.124	1164.	49.	653.	19597.
1985	19515.	39.0	9.76	1.344	16.467	1392.	58.	711.	21336.
1986	18000.	36.0	9.00	1.239	17.707	1284.	54.	765.	22943.
1987	17000.	34.0	8.50	1.170	18.877	1213.	51.	815.	24460.
1988	20000.	40.0	10.00	1.377	20.254	1427.	59.	875.	26243.
1989	19000.	38.0	9.50	1.308	21.562	1356.	56.	931.	27938.
1990	21000.	42.0	10.50	1.446	23.008	1498.	62.	994.	29811.
1991	28000.	56.0	14.00	1.928	24.936	1998.	83.	1077.	32308.
1992	22000.	44.0	11.00	1.515	26.451	1570.	65.	1142.	34270.
1993	24000.	48.0	12.00	1.652	28.103	1712.	71.	1214.	36411.
1994	30000.	60.0	15.00	2.065	30.169	2140.	89.	1303.	39086.
1995	24000.	48.0	12.00	1.652	31.821	1712.	71.	1374.	41227.
1996	30000.	60.0	15.00	2.065	33.886	2140.	89.	1463.	43903.
1997	30000.	60.0	15.00	2.065	35.952	2140.	89.	1553.	46578.
1998	33000.	66.0	16.50	2.272	38.224	2355.	98.	1651.	49521.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 75: 25
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. ANNUAL ACRE-FEET/PLANT (Eastern)
   1978-1979 = 242
   1980-1998 = 142.7
4. ANNUAL DRY WASTE/PLANT - EASTERN COAL
   1978-1979 = 2.334×10^5 tons @ 80% SCRUBBING
   (3.5% Sulfur, 14% Ash, 12,000 Btu/lb; No Wash)
   1980-1998 = 1.377×10^5 tons @ 85% SCRUBBING
   (3.5% Sulfur, 14% Ash, 13,200 Btu/lb;
   40% of Sulfur Removed By Wash)

(continued)

TABLE B-3d. 0.5-LB $SO_2/10^6$ BTU: 25 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL WITH 40% WASH						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	19.89	0.0	0.0	0.	0.	0.	0.
1979	15544.	31.1	18.65	0.0	0.0	0.	0.	0.	0.
1980	21101.	42.2	10.55	0.431	0.431	291.	12.	12.	364.
1981	15639.	31.3	7.82	0.320	0.751	216.	9.	21.	634.
1982	17854.	35.7	8.93	0.365	1.116	246.	10.	31.	942.
1983	18079.	36.2	9.04	0.370	1.486	249.	10.	42.	1254.
1984	16319.	32.6	8.16	0.334	1.819	225.	9.	51.	1535.
1985	19515.	39.0	9.76	0.399	2.218	269.	11.	62.	1872.
1986	18000.	36.0	9.00	0.368	2.586	248.	10.	73.	2182.
1987	17000.	34.0	8.50	0.348	2.934	235.	10.	83.	2476.
1988	20000.	40.0	10.00	0.409	3.343	276.	12.	94.	2821.
1989	19000.	38.0	9.50	0.388	3.731	262.	11.	105.	3148.
1990	21000.	42.0	10.50	0.429	4.161	290.	12.	117.	3511.
1991	28000.	56.0	14.00	0.572	4.733	386.	16.	133.	3994.
1992	22000.	44.0	11.00	0.450	5.183	304.	13.	146.	4373.
1993	24000.	48.0	12.00	0.491	5.674	331.	14.	160.	4787.
1994	30000.	60.0	15.00	0.613	6.287	414.	17.	177.	5305.
1995	24000.	48.0	12.00	0.491	6.778	331.	14.	191.	5719.
1996	30000.	60.0	15.00	0.613	7.391	414.	17.	208.	6236.
1997	30000.	60.0	15.00	0.613	8.004	414.	17.	225.	6754.
1998	33000.	66.0	16.50	0.675	8.679	455.	19.	244.	7323.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 - 35: 65
   1979 - 40: 60
   1980-1998 - 75: 25
2. ACRES REQUIRED - ACRE-FEET x $\frac{1.25}{30}$
3. 40% COAL WASH:
   ANNUAL DRY WASTE - 4.089 x 10^4 tons
   ACRE-FEET - 27.6

(continued)

TABLE B-3d. 0.5-LB $SO_2/10^6$ BTU: 25 PERCENT EASTERN COAL (continued)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY, MN	ANNUAL NUMBER OF EQUIV PLANTS	WESTERN COAL						
			NUMBER OF EQUIV PLANTS	ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL DRY WASTE, MILLION TONS	ANNUAL WET VOL, ACRE-FT	ANNUAL ACRES	TOTAL ANNUAL ACRES REQUIRED	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	10.71	1.009	1.009	1046.	44.	44.	1307.
1979	15544.	31.1	12.44	1.172	2.181	1214.	51.	94.	2825.
1980	21101.	42.2	31.65	3.545	5.726	3672.	153.	247.	7415.
1981	15639.	31.3	23.46	2.627	8.353	2721.	113.	361.	10816.
1982	17854.	35.7	26.78	2.999	11.352	3107.	129.	490.	14699.
1983	18079.	36.2	27.12	3.037	14.390	3146.	131.	621.	18632.
1984	16319.	32.6	24.48	2.742	17.131	2840.	118.	739.	22181.
1985	19515.	39.0	29.27	3.279	20.410	3396.	141.	881.	26426.
1986	18000.	36.0	27.00	3.024	23.434	3132.	131.	1011.	30341.
1987	17000.	34.0	25.50	2.856	26.290	2958.	123.	1135.	34036.
1988	20000.	40.0	30.00	3.360	29.650	3480.	145.	1280.	36388.
1989	19000.	38.0	28.50	3.192	32.842	3306.	138.	1417.	42521.
1990	21000.	42.0	31.50	3.528	36.370	3654.	152.	1570.	47088.
1991	28000.	56.0	42.00	4.704	41.074	4872.	203.	1773.	53178.
1992	22000.	44.0	33.00	3.696	44.770	3828.	160.	1932.	57963.
1993	24000.	48.0	36.00	4.032	48.802	4176.	174.	2106.	63183.
1994	30000.	60.0	45.00	5.040	53.842	5220.	218.	2324.	69706.
1995	24000.	48.0	36.00	4.032	57.874	4176.	174.	2498.	74926.
1996	30000.	60.0	45.00	5.040	62.914	5220.	218.	2715.	81453.
1997	30000.	60.0	45.00	5.040	67.954	5220.	218.	2933.	87979.
1998	33000.	66.0	49.50	5.544	73.498	5742.	239.	3172.	95156.

NOTES:

1. COAL BURNING RATIO (West: East)
   1978 = 35: 65
   1979 = 40: 60
   1980-1998 = 75: 25
2. ACRES REQUIRED = ACRE-FEET x $\frac{1.25}{30}$
3. (0.8% Sulfur, 6% Ash, 8000 Btu/lb) WESTERN COAL
   1978-1979 = 9.421 x 10^4 tons @ 40% SCRUBBING
   1980-1998 = 1.120 x 10^5 tons @ 75% SCRUBBING
4. ANNUAL ACRE-FEET/PLANT (Western)
   1978-1979 = 97.64
   1980-1998 = 116.0

(continued)

TABLE B-3d. 0.5-LB $SO_2/10^6$ BTU: 25 PERCENT EASTERN COAL (concluded)

YEAR	ANNUAL INSTALLED GENERATING CAPACITY MW	ANNUAL NUMBER OF EQUIV PLANTS	EASTERN COAL			WESTERN COAL			NATIONWIDE		
			ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	ANNUAL DRY WASTE, MILLION TONS	ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED	TOTAL ANNUAL DRY WASTE, MILLION TONS	TOTAL ANNUAL ACRES	TOTAL ANNUAL ACREAGE REQUIRED
1978	15303.	30.6	4.643	201.	6018.	1.009	44.	1307.	6.	244.	7325.
1979	15544.	31.1	8.997	389.	11660.	2.181	94.	2825.	11.	483.	14485.
1980	21101.	42.2	10.450	451.	13542.	5.726	247.	7415.	16.	699.	20957.
1981	15639.	31.3	11.526	498.	14937.	8.353	361.	10816.	20.	858.	25753.
1982	17854.	35.7	12.756	551.	16530.	11.352	490.	14699.	24.	1041.	31229.
1983	18079.	36.2	14.000	605.	18142.	14.390	621.	18632.	28.	1226.	36774.
1984	16319.	32.6	15.124	653.	19597.	17.131	739.	22181.	32.	1393.	41779.
1985	19515.	39.0	16.467	711.	21338.	20.410	881.	26426.	37.	1592.	47764.
1986	18000.	36.0	17.707	765.	22943.	23.434	1011.	30341.	41.	1776.	53284.
1987	17000.	34.0	18.877	815.	24460.	26.290	1135.	34038.	45.	1950.	58498.
1988	20000.	40.0	20.254	875.	26243.	29.650	1280.	38388.	50.	2154.	64631.
1989	19000.	38.0	21.562	931.	27938.	32.842	1417.	42521.	54.	2349.	70459.
1990	21000.	42.0	23.008	994.	29811.	36.370	1570.	47088.	59.	2563.	76899.
1991	28000.	56.0	24.936	1077.	32308.	41.074	1773.	53178.	66.	2850.	85486.
1992	22000.	44.0	26.451	1142.	34270.	44.770	1932.	57963.	71.	3074.	92234.
1993	24000.	48.0	28.103	1214.	36411.	48.802	2106.	63183.	77.	3320.	99594.
1994	30000.	60.0	30.169	1303.	39086.	53.842	2324.	69708.	84.	3626.	108795.
1995	24000.	48.0	31.821	1374.	41227.	57.874	2498.	74928.	90.	3872.	116155.
1996	30000.	60.0	33.886	1463.	43903.	62.914	2715.	81453.	97.	4179.	125356.
1997	30000.	60.0	35.952	1553.	46578.	67.954	2933.	87979.	104.	4485.	134557.
1998	33000.	66.0	38.224	1651.	49521.	73.498	3172.	95156.	112.	4823.	144677.

APPENDIX C

PROJECTED NATIONWIDE QUANTITIES OF SULFURIC ACID OR ELEMENTAL SULFUR PRODUCED FROM REGENERABLE SYSTEMS

Projections of the number of regenerable scrubber systems reflect a wide range of uncertainty.[1] Therefore, estimates were made to bound the potential application of regenerable systems. The cumulative amounts of sulfuric 100% acid or sulfur produced assuming 5, 25, and 50 percent regenerable scrubbing during the 1978-1998 interval were used to calculate the quantities produced of either of the two chemicals based on conditions defined in Table 22 and quantities in Appendix B. The cumulative totals of 100% sulfuric acid, or sulfur capable of being produced as a result from this assumption and applying the three alternative NSPS standards, are tabulated in Table C-1.

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[1] Summary Report: Flue Gas Desulfurization Systems, Prepared for U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, Contract No. 68-02-1321, by PEDCo Environmental Specialists, Inc., Cincinnati, Ohio (January-March 1977).

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TABLE C-1. PROJECTED ANNUAL NATIONWIDE QUANTITIES OF SULFURIC ACID OR ELEMENTAL SULFUR PRODUCED FROM VARIOUS ASSUMED FRACTIONS OF THE TOTAL SO_2 SCRUBBED

PERCENT OF SCRUBBERS THAT ARE REGENERABLE

	0%		5%			25%			50%		
Year	Non-regenerable Waste Produced,[a] tons X 10^6	% Ash[b]	Non-Regen Waste,[c] tons X 10^6	Sulfuric Acid, tons X 10^6	Sulfur, tons X 10^6	Non-Regen Waste, tons X 10^6	Sulfuric Acid, tons X 10^6	Sulfur, tons X 10^6	Non-Regen Waste, tons X 10^6	Sulfuric Acid, tons X 10^6	Sulfur, tons X 10^6
Current NSPS: 1.2 lb $SO_2/10^6$ Btu											
1980	7.205	55.5	7.045	0.112	0.036	6.403	0.561	0.183	5.602	1.122	0.366
1983	6.175	56.0	6.039	0.095	0.031	5.496	0.475	0.155	4.817	0.951	0.310
1988	6.830	56.2	6.680	0.105	0.034	6.082	0.524	0.171	5.334	1.047	0.342
1993	8.195	56.3	8.016	0.125	0.041	7.300	0.627	0.205	6.404	1.253	0.409
1998	11.270	56.4	11.025	0.172	0.056	10.042	0.860	0.281	8.814	1.720	0.562
Alternative NSPS: 90% SO_2 Removal											
1980	8.032	50.1	7.832	0.140	0.046	7.030	0.701	0.229	6.028	1.403	0.458
1983	6.880	50.4	6.709	0.119	0.039	6.027	0.597	0.195	5.174	1.194	0.390
1988	7.613	50.5	7.433	0.132	0.043	6.671	0.659	0.215	5.729	1.319	0.431
1993	9.135	50.6	8.909	0.158	0.052	8.007	0.790	0.258	6.879	1.579	0.516
1998	12.562	50.6	12.252	0.217	0.071	11.011	1.086	0.354	9.460	2.172	0.709
Alternative NSPS: 0.5 lb $SO_2/10^6$ Btu											
1980	5.323	55.8	5.205	0.082	0.027	4.735	0.412	0.134	4.147	0.824	0.269
1983	4.560	56.1	4.460	0.070	0.023	4.060	0.350	0.114	3.559	0.701	0.229
1988	5.045	56.3	4.935	0.077	0.025	4.494	0.386	0.126	3.943	0.771	0.252
1993	6.054	56.4	5.922	0.092	0.030	5.394	0.462	0.151	4.734	0.924	0.302
1998	8.325	56.4	8.144	0.127	0.041	7.417	0.635	0.207	6.510	1.270	0.415

[a] Total dry waste from 100% nonregenerable scrubbing (including ash) from Appendix B, short tons

[b] Average percent ash in the nonregenerable waste

[c] Solid waste (dry tons) from the fraction of nonregenerable processes (including ash)

APPENDIX D

CHEMICAL CHARACTERIZATION DATA

The results from the chemical analyses[1] performed on the liquid and solid portions of flue gas desulfurization (FGD) sludge samples taken at various locations within the waste streams of FGD scrubbing systems are presented. The concentration values, as presented, represent either the mean or median of a minimum of three and a possible maximum of nine independent measurements.

Tables D-1 through D-13 present results from chemical analyses of the liquid sampled from various locations within five scrubbing systems. Tables D-14 through D-17 summarize the results for four of the scrubbing systems. Tables D-18 through D-27 are the solids analyses available from these scrubber systems.

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[1] J. Rossoff et al., Disposal of By-Products from Nonregenerable Flue Gas Desulfurization Systems: Second Progress Report, EPA-600/7-77-052, U.S. Environmental Protection Agency, Washington, D.C. (May 1977)

TABLE D-1. ANALYSIS OF SCRUBBER LIQUORS FROM TVA SHAWNEE STEAM PLANT

Date: 1 Feb 1973
Conc: mg/ℓ

TCA Scrubber-Limestone System

Scrubber Liquor Constituents	Sampling Locations			
	Process Makeup Water	Scrubber Effluent (Separated)	Scrubber Effluent (Retained)	Clarifier Effluent (Retained)
Aluminum		1.7	0.7	0.2
Arsenic	< 0.2	1.2	0.8	1.7
Beryllium	< 0.0005	0.006	0.015	0.012
Cadmium	< 0.0005	0.009	0.001	0.004
Calcium		1800	1600	860
Chromium	< 0.001	0.025	0.006	0.015
Copper	0.012	0.041	0.021	0.051
Lead	< 0.005	0.030	0.026	0.039
Magnesium		100	53	42
Mercury	0.007	-	-	-
Potassium	-	-	24	28
Selenium	< 0.01	0.35	0.15	0.54
Sodium	-	-	12	10
Zinc	< 0.2	4	10	11
Chloride	-	-	1000	900
Fluoride	-	-	-	3.4
Sulfate	-	-	2500	1280
Sulfite	-	460	160	180
TDS	-	5800	5400	3200
pH	7.4	2.3	7.8	7.2

Dash indicates sample not analyzed or insufficient sample.

TABLE D-2. ANALYSIS OF SCRUBBER LIQUORS FROM TVA SHAWNEE STEAM PLANT

Date: 12 Jul 1973
Conc: mg/ℓ

TCA Scrubber-Limestone System

Scrubber Liquor Constituents	Sampling Locations			
	Process Makeup Water	Scrubber Effluent (Separated)	Scrubber Effluent (Retained)	Clarifier Effluent (Retained)
Aluminum	0.04	1.5	0.5	0.3
Arsenic	0.02	2.0	2.0	1.8
Beryllium	0.0012	0.020	0.028	0.026
Cadmium	0.0005	0.0072	0.0092	0.0089
Calcium	-	2200	3100	2600
Chromium	0.001	0.13	0.17	0.20
Copper	0.005	0.060	0.064	0.052
Lead	0.005	0.19	0.32	0.28
Magnesium	-	100	50	160
Mercury	0.0001	0.11	0.14	0.04
Potassium	-	-	37	43
Selenium	0.01	2.0	3.1	2.7
Sodium	-	-	80	87
Zinc	0.4	29	38	27
Chloride	20	4800	6000	5000
Fluoride	1.2	0.4	0.25	3.1
Sulfate	-	-	2100	1800
Sulfite	-	-	110	90
TDS			11,500	10,200
pH	7.3	2.44	8.4	9.01

Dash indicates sample not analyzed or insufficient sample.

TABLE D-3. ANALYSIS OF SCRUBBER LIQUORS FROM TVA SHAWNEE STEAM PLANT

Date: 27 Nov 1973

Conc: mg/l

TCA Scrubber-Limestone System

Scrubber Liquor Constituents	Sampling Locations			
	Process Makeup Water	Scrubber Effluent (Separated)	Scrubber Effluent (Retained)	Clarifier Effluent (Retained)
Aluminum	-	-	-	-
Arsenic	< 0.001	0.14	0.31	0.28
Beryllium	-	0.01	0.01	0.004
Cadmium	-	0.04	0.013	0.004
Calcium	-	1600	1800	1600
Chromium	-	0.040	0.12	0.51
Copper	-	0.05	0.45	0.41
Lead	0.0005	0.006	0.06	0.12
Magnesium	-	-	900	600
Mercury	-	-	-	0.05
Potassium	-	6.3	5.4	5.9
Selenium	-	0.2	0.2	0.2
Sodium	-	63	67	59
Zinc	0.13	0.84	0.62	0.35
Chloride	-	3100	3700	3100
Fluoride	-	2.3	2.0	2.4
Sulfate	-	2400	3000	2100
Sulfite	-	1.7	3.0	2.1
TDS	-	8500	12,000	11,000
pH	-	6.7	5.9	9.5

Dash indicates sample not analyzed or insufficient sample.

TABLE D-4. ANALYSIS OF SCRUBBER LIQUORS FROM TVA SHAWNEE STEAM PLANT

Date: 15 Jun 1974
Conc: mg/ℓ

TCA Scrubber-Limestone System

Scrubber Liquor Constituents	Sampling Locations				
	Process Makeup Water	Scrubber Effluent (Separated)	Scrubber Effluent (Retained)	Clarifier Effluent (Separated)	Clarifier Effluent (Retained)
Aluminum	-	-	2.7	-	0.6
Arsenic	0.004	0.39	0.39	0.13	0.14
Beryllium	0.004	0.068	0.074	0.052	0.054
Cadmium	0.005	0.006	0.004	0.004	0.003
Calcium	-	660	840	520	600
Chromium	0.002	0.16	0.13	0.09	0.09
Copper	0.01	0.02	0.02	0.01	0.01
Lead	0.006	0.35	0.30	0.21	0.25
Magnesium	-	2800	2800	2600	2750
Mercury	<0.05	<0.05	<0.05	<0.05	<0.05
Potassium	-	-	-	32	41
Selenium	-	<0.2	0.08	0.1	<0.2
Sodium	-	-	-	76	79
Zinc	-	0.04	0.03	0.03	0.02
Chloride	-	3600	3300	2300	2250
Fluoride	-	2.3	2.2	6.5	6.2
Sulfate	-	9000	10,000	10,000	9800
Sulfite	-	1550	1150	55	110
TDS		16,500	17,800	15,000	15,500
pH	7.1	4.6	5.5	8.0	8.3

Dash indicates sample not analyzed or insufficient sample.

TABLE D-5. ANALYSIS OF SCRUBBER LIQUOR FROM SCE MOHAVE GENERATING STATION

Date: 30 Mar 1973

Conc: mg/ℓ

TCA Scrubber-Limestone System

Scrubber Liquor Constituents	Sampling Locations			
	Process Makeup Water	Scrubber Effluent	Scrubber Recirculation	Centrifuge Effluent
Aluminum	-	-	0.04	-
Arsenic	0.01	0.03	0.038	0.028
Beryllium	0.011	0.03	0.03	0.02
Cadmium	0.07	0.05	0.05	0.05
Calcium	610	200	300	180
Chromium	0.03	0.23	0.3	0.25
Copper	-	0.08	0.2	0.56
Lead	0.003	0.06	0.11	0.04
Magnesium	230	310	300	390
Mercury	< 0.05	0.0012	0.00037	< 0.005
Potassium	130	100	100	100
Selenium	< 0.0005	0.12	0.11	0.1
Sodium	2700	30,000	29,000	29,000
Zinc	-	0.12	0.18	0.18
Chloride	4050	30,600	28,000	33,000
Sulfate	2500	22,000	24,000	16,650
TDS	12,700	95,000	94,800	92,500
pH	9.1	7.8	7.5	6.7

Dash indicates sample not analyzed or insufficient sample.

TABLE D-6. ANALYSIS OF SCRUBBER LIQUORS FROM TVA SHAWNEE STEAM PLANT

Date: 19 Mar 1974

Conc: mg/ℓ

Venturi-Spray Tower-Lime System

Scrubber Liquor Constituents	Sampling Locations						
	Process Makeup Water	Scrubber Effluent (Separated)	Scrubber Effluent (Retained)	Clarifier Effluent (Separated)	Clarifier Effluent (Retained)	Filter Effluent (Filtrate)	Lime Slurry
Aluminum	-	0.22	0.06	0.12	0.03	0.08	0.21
Arsenic	< 0.004	0.15	0.21	0.17	0.30	0.15	0.10
Beryllium	0.003	0.050	0. 0.023	0.020	0.027	0.026	0.004
Cadmium	-	0.02	0.01	0.02	0.03	0.03	0.01
Calcium	-	980	900	840	800	660	720
Chromium	0.004	0.02	0.03	0.01	0.02	0.03	0.01
Copper	0.01	0.08	0.10	0.04	0.07	0.05	0.02
Lead	0.03	0.03	0.008	0.04	0.06	0.01	0.009
Magnesium	-	53	56	28	25	24	1
Mercury	0.001	0.10	0.04	0.09	0.07	0.07	0.07
Potassium	-	8.4	8.6	6.8	13	11	29
Selenium	0.003	0.08	0.10	0.08	0.09	0.09	0.08
Sodium	-	71	33	36	28	36	88
Zinc	0.03	0.09	0.07	0.02	0.01	0.01	0.01
Chloride	-	1230	1290	1210	1040	1050	720
Fluoride	-	< 0.3	< 0.3	1.4	1.4	1.4	40
Sulfate	-	1000	800	1350	1000	900	100
Sulfite	-	450	0.8	1.8	2.2	1.7	-
TDS	-	3500	3300	3500	3200	2800	1800
pH	7.8	5.2	5.4	9.5	9.0	9.4	12.7

Dash indicates sample not analyzed or insufficient sample

TABLE D-7. ANALYSIS OF SCRUBBER LIQUORS FROM TVA SHAWNEE STEAM PLANT

Date: 16 May 1974

Conc: mg/ℓ

Venturi-Spray Tower-Lime System

Scrubber Liquor Constituents	Sampling Locations				
	Scrubber Effluent (Separated)	Scrubber Effluent (Retained)	Clarifier Effluent (Separated)	Clarifier Effluent (Retained)	Filter Effluent (Filtrate)
Aluminum	0.12	0.5	0.5	0.3	0.1
Arsenic	0.15	0.04	0.06	0.03	0.01
Beryllium	0.05	0.04	0.20	0.07	0.05
Cadmium	0.04	0.006	0.004	0.004	0.013
Calcium	2360	2500	2340	2580	2420
Chromium	0.02	0.008	0.03	0.01	0.02
Copper	0.03	0.02	0.06	0.07	0.04
Lead	0.13	0.11	0.14	0.13	0.13
Magnesium	220	215	210	220	200
Mercury	<0.05	<0.05	<0.05	<0.05	<0.05
Potassium	21	24	30	29	27
Selenium	1.9	1.7	1.5	1.9	1.9
Sodium	108	106	108	104	109
Zinc	0.02	0.03	0.02	0.02	0.02
Chloride	4400	4400	4300	4200	4200
Fluoride	1.5	2.2	2.6	4.5	3.0
Sulfate	1500	1400	1350	1350	1250
Sulfite	3.0	1.8	4.6	2.3	2.7
TDS	8700	8200	8000	7800	8400
pH	5.6	7.0	8.4	9.1	8.8

Dash indicates sample not analyzed or insufficient sample.

TABLE D-8. ANALYSIS OF SCRUBBER LIQUORS FROM TVA SHAWNEE STEAM PLANT

Date: 27 Jun 1974

Conc: mg/ℓ

Venturi-Spray Tower-Lime System

Scrubber Liquor Constituents	Sampling Locations			
	Scrubber Effluent (Separated)	Scrubber Effluent (Retained)	Clarifier Effluent (Retained)	Filter Effluent (Filtrate)
Aluminum	1.54		< 0.1	0.24
Arsenic	0.04	<0.01	0.02	0.02
Beryllium	<0.002	<0.002	< 0.002	< 0.002
Cadmium	0.12	0.12	0.11	0.11
Calcium	3000	3060	2820	2520
Chromium	0.04	0.04	0.04	0.03
Copper	0.01	0.005	< 0.002	0.002
Lead	0.33	0.37	0.39	0.33
Magnesium	420	410	450	420
Mercury	<0.001	< 0.001	< 0.001	< 0.001
Potassium	25	27	32	28
Selenium	< 0.02	< 0.02	< 0.02	< 0.02
Sodium	126	122	125	127
Zinc	0.18	0.14	0.11	0.08
Chloride	5800	5200	5900	4900
Fluoride	0.2	0.9	4.0	3.3
Sulfate	800	700	800	800
Sulfite	12	< 0.6	0.8	0.9
TDS	10,800	10,000	10,400	9400
pH	2.7	5.4	9.0	8.7

TABLE D-9. ANALYSIS OF SCRUBBER LIQUORS FROM APS CHOLLA POWER PLANT

Date: 1 April 1974
Conc: mg/ℓ

Venturi-Absorber-Limestone System

Scrubber Liquor Constituents	Sampling Locations			
	Process Makeup Water	Slurry Tank (Separated)	Slurry Tank (Retained)	Absorbent Tower Effluent
Aluminum	-	2	2	0.6
Arsenic	<0.004	<0.004	<0.004	<0.004
Beryllium	0.10	0.14	0.18	0.08
Cadmium	0.08	0.011	0.009	0.007
Calcium	140	680	700	580
Chromium	0.02	0.14	0.21	0.02
Copper	0.04	0.20	0.19	0.03
Lead	0.004	0.01	0.01	0.02
Magnesium	5.8	3	6	7
Mercury	0.04	0.07	0.13	0.007
Potassium	-	14	16	-
Selenium	1.2	2.2	2.5	1.0
Sodium	-	2150	2250	800
Zinc	0.05	0.11	0.07	0.02
Chloride	-	1700	1430	620
Fluoride	-	0.7	0.6	2.4
Sulfate	300	4000	4000	2200
Sulfite	<1	0.9	<1	1
TDS	-	8700	9100	4300
pH	-	3.04	4.3	6.6

Dash indicates sample not analyzed or insufficient sample.

TABLE D-10. ANALYSIS OF SCRUBBER LIQUORS FROM APS CHOLLA POWER PLANT

Date: 7 Nov 1974

Conc: mg/ℓ

Venturi-Absorber-Limestone System

Scrubber Liquor Constituents	Sampling Locations		
	Process Makeup Water	Slurry Tank (Separated)	Absorbent Tower Effluent
Aluminum	-	-	2.1
Arsenic	<0.004	-	0.02
Beryllium	<0.003	0.038	<0.003
Cadmium	0.0065	0.044	0.012
Calcium	27	770	390
Chromium	<0.004	0.024	0.004
Copper	0.014	0.16	0.010
Lead	0.07	0.37	0.15
Magnesium	-	4	9
Mercury	0.0015	<0.05	<0.5
Potassium	9	28	8
Selenium	0.0006	<0.0006	0.033
Sodium	570	1650	370
Zinc	0.027	0.47	0.036
Chloride	940	4200	760
Fluoride	1.1	1.5	1.0
Sulfate	250	3750	1360
Sulfite	2.5	3500	21
TDS	2438	14,000	3300
pH	8.4	3.4	6.8

Dash indicates sample not analyzed or insufficient sample.

TABLE D-11. ANALYSIS OF SCRUBBER LIQUORS FROM DLC PHILLIPS STATION

Date: 4 Oct 1973
Conc: mg/ℓ

Venturi-Lime System

Scrubber Liquor Constituents	Sampling Locations			
	Process Makeup Water	Thickener Overflow	Thickener Underflow	
Aluminum	-	-	-	
Arsenic	<0.001	0.085	0.09	
Beryllium	<0.0005	0.012	0.012	
Cadmium	0.003	0.022	0.023	
Calcium	50	1300	1400	
Chromium	<0.001	0.037	0.040	
Copper	0.003	0.06	0.07	
Lead	0.0012	0.08	0.18	
Magnesium	40	220	410	
Mercury	0.003	0.09	0.05	
Potassium	-	20	22	
Selenium	<0.01	0.8	0.8	
Sodium	-	1680	2400	
Zinc	0.013	0.12	0.09	
Chloride	-	1800	2700	
Fluoride	-	4.8	2.6	
Sulfate	-	4500	6450	
Sulfite	-	<1	27	
TDS	-	9400	14,000	
pH		9.2	7.1	

Dash indicates sample not analyzed or insufficient sample.

TABLE D-12. ANALYSIS OF SCRUBBER LIQUORS FROM DLC PHILLIPS STATION

Date: 17 Jun 1974

Conc: mg/ℓ

Venturi-Lime System

Scrubber Liquor Constituents	Sampling Locations				
	Process Makeup Water	Scrubber Effluent	Thickener Overflow	Thickener Underflow	Pond Sludge Liquid
Aluminum	-	-	-	-	-
Arsenic	<0.004	0.06	<0.004	<0.004	<0.004
Beryllium	<0.0002	0.002	0.002	0.003	0.002
Cadmium	-	0.1	-	0.05	-
Calcium	-	660	680	600	600
Chromium	-	-	-	-	-
Copper	-	-	-	-	-
Lead	<0.006	0.05	0.06	<0.04	0.04
Magnesium	-	-	-	-	-
Mercury	0.0002	0.0004	0.0002	0.0002	0.0004
Potassium	-	10	2.6	26	22
Selenium	0.005	0.33	0.20	0.028	0.095
Sodium	-	440	380	320	340
Zinc	-	-	-	-	-
Chloride	-	540	350	470	420
Fluoride	-	8	2	10	7
Sulfate		2700	2800	2720	1000
Sulfite	-	1.7	0.8	20	4.8
TDS	-	4600	4400	4200	4000
pH	-	8.9	4.1	10.7	10.4

TABLE D-13. ANALYSIS OF SCRUBBER LIQUORS FOR GM UTILITY BOILER

Date: 18 Jul 1974
Conc: mg/ℓ

Bubble Cap Tray-Double Alkali System

Scrubber Liquor Constituents	Sampling Locations						
	Process Makeup Water	Mix Tank No. 2 Underflow	Clarifier No. 1 Overflow	Clarifier No. 1 Underflow	Clarifier No. 2 Overflow	Clarifier No. 2 Underflow	Filter Effluent (Filtrate)
Aluminum	-	-	-	-	-	-	-
Arsenic	<0.004	<0.004	<0.004	-	<0.004	<0.004	<0.004
Beryllium	<0.002	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
Cadmium	<0.005	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Calcium	-	420	640	640	290	300	470
Chromium	<0.005	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Copper	<0.005	0.06	0.02	0.06	0.05	0.06	0.06
Lead	<0.02	0.42	0.56	0.55	0.55	0.53	0.52
Magnesium	-	-	-	-	-	-	-
Mercury	0.0004	0.002	<0.0002	0.0009	0.0002	0.0014	0.005
Potassium	-	95	140	110	120	160	-
Selenium	0.002	0.15	0.14	0.087	0.19	0.26	0.075
Sodium	-	-	-	20,000	20,000	-	20,000
Zinc	0.07	0.06	0.09	0.63	0.05	0.06	0.59
Chloride	-	3500	3700	4400	3100	4300	5200
Fluoride	-	58	96	82	92	46	58
Sulfate	-	25,000	34,000	30,000	33,000	30,000	35,000
Sulfite	-	400	250	160	340	260	140
TDS	-	51,000	67,000	59,000	62,000	68,000	65,000
pH		12.6	12.6	12.8	12.5	12.5	12.7

Dash indicates sample not analyzed or insufficient sample

TABLE D-14. ANALYSES OF SCRUBBER LIQUORS FROM TVA SHAWNEE STEAM PLANT: TCA SCRUBBER SYSTEM

Scrubber liquor constituents[a]	In-process data		Potential discharge point data	
	Sample location			
	Scrubber effluent		Clarifier underflow	
	Sample date			
	11/27/73	6/15/74	11/27/73	6/15/74
Aluminum (Al)	--	2.7	--	0.6
Antimony (Sb)	--	2.0	--	1.4
Arsenic (As)	0.2	0.4	0.3	0.1
Beryllium (Be)	0.01	0.07	0.004	0.05
Boron (B)	--	--	--	--
Cadmium (Cd)	0.04	0.005	0.004	0.004
Calcium (Ca)	1800	840	1600	520
Chromium (Cr) (total)	0.04	0.16	0.5	0.09
Cobalt (Co)	--	0.16	--	0.10
Copper (Cu)	0.05	0.02	0.4	0.01
Iron (Fe)	--	0.35	--	0.02
Lead (Pb)	0.06	0.35	0.12	0.23
Magnesium (Mg)	900	2800	600	2750
Manganese (Mn)	--	--	--	--
Mercury (Hg)	--	<0.5	0.05	<0.05
Molybdenum (Mo)	--	--	--	--
Nickel (Ni)	0.16	0.44	0.50	0.33
Potassium (K)	6.3	--	5.9	41
Selenium (Se)	0.2	--	0.2	0.1
Silicon (Si)	--	--	--	--
Silver (Ag)	--	0.008	--	0.005
Sodium (Na)	63	--	59	--
Tin (Sn)	--	--	--	--
Vanadium (V)	--	--	--	--
Zinc (Zn)	0.84	0.03	0.35	0.02
Total carbonate	--	--	--	--
Chloride (Cl)	3400	3300	3100	2300
Fluoride (F)	2.3	2.3	2.4	6.5
Sulfite	--	1400	--	80
Sulfate	2700	9500	2100	10000
Phosphate	<0.1	<0.1	<0.1	<0.1
Total nitrogen	<0.005	<0.005	<0.005	<0.005
Chemical oxygen demand	--	--	--	--
Total dissolved solids	12000	17800	11000	15000
Total alkalinity	--	--	150	--
Conductance, mho/cm	--	0.027	--	0.015
Turbidity, Jackson units	< 3	< 3	< 3	< 3
pH	5.90	4.64	9.50	7.96

[a] Concentration in milligrams per liter unless otherwise indicated.

TABLE D-15. ANALYSES OF SCRUBBER LIQUORS FROM TVA SHAWNEE STEAM PLANT (VENTURI AND SPRAY TOWER SCRUBBER SYSTEM)

Scrubber liquor constituents[a]	In-process data			Potential discharge point data					
	Sample location								
	Scrubber effluent			Clarifier underflow			Drum vacuum filter filtrate		
	Sample date								
	3/19/74	5/16/74	6/27/74	3/19/74	5/16/74	6/27/74	3/19/74	5/16/74	6/27/74
Aluminum (Al)	0.22	0.12	1.54	0.03	0.3	<0.1	0.08	0.1	0.24
Antimony (Sb)	0.39	2.1	1.01	0.55	2.3	1.11	0.46	1.6	1.01
Arsenic (As)	0.15	0.15	0.04	0.30	0.03	0.02	0.15	0.01	0.02
Beryllium (Be)	0.05	0.05	<0.002	0.027	0.07	<0.002	·0.026	0.05	<0.002
Boron (B)	--	--	56	--	--	46	--	--	41
Cadmium (Cd)	0.02	0.04	0.12	0.03	0.004	0.11	0.03	0.013	0.10
Calcium (Ca)	980	2360	3000	800	2580	2820	660	2420	2520
Chromium (Cr) (total)	0.02	0.02	0.04	0.02	0.01	0.04	0.03	0.02	0.03
Cobalt (Co)	--	0.6	0.31	--	0.6	0.32	--	0.7	0.35
Copper (Cu)	0.08	0.03	0.01	0.07	0.07	<0.002	0.05	0.04	<0.002
Iron (Fe)	0.77	0.14	1.81	0.08	0.27	0.10	0.02	0.10	0.06
Lead (Pb)	0.03	0.12	0.33	0.06	0.13	0.39	0.01	0.13	0.33
Magnesium (Mg)	53	220	420	25	220	450	24	200	420
Manganese (Mn)	--	0.4	--	--	0.09	0.46	--	·0.2	0.84
Mercury (Hg)	0.10	<0.05	<0.001	0.07	<0.05	<0.001	0.07	<0.05	<0.001
Molybdenum (Mo)	--	--	6.1	--	--	6.3	--	--	5.3
Nickel (Ni)	0.5	0.25	0.29	0.08	0.23	0.24	0.05	0.31	0.21
Potassium (K)	8.4	21	25	13	29	32	11	27	28
Selenium (Se)	0.08	1.9	<0.02	0.09	1.9	<0.02	0.09	1.9	<0.02
Silicon (Si)	0.4	1.8	2.1	0.4	1.8	1.0	0.2	1.6	2.7
Silver (Ag)	0.09	0.01	0.03	0.06	0.01	0.03	0.06	0.01	0.02
Sodium (Na)	33	108	126	36	104	125	36	109	127
Tin (Sn)	--	--	3.5	--	--	3.5	--	--	3.1
Vanadium (V)	--	--	--	<0.001	--	--	--	--	--
Zinc (Zn)	0.09	0.02	0.18	0.01	0.02	0.11	0.01	0.02	0.08
Total carbonate	<10	<10	<10	<10	<10	<10	<10	<10	<10
Chloride (Cl)	1230	4400	5400	1040	4200	5900	1050	4200	4900
Fluoride (F)	<0.3	1.5	0.2	1.4	4.5	4.0	1.4	3.0	3.3
Sulfite	450	3.0	12	2.2	2.3	0.8	1.7	2.7	0.9
Sulfate	1000	1500	1800	1000	1350	800	900	1250	800
Phosphate	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
Total nitrogen	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Chemical oxygen demand	220	--	149	160	--	98	85	--	89
Total dissolved solids	3500	8700	10800	3200	7800	10400	2800	8400	9400
Total alkalinity	54	--	63	49	--	82	57	--	76
Conductance, mho/cm	0.006	0.013	0.019	0.004	0.014	0.014	0.004	0.012	0.013
Turbidity, Jackson units	<3	<3	<3	<3	<3	<3	<10	<10	<10
pH	5.19	5.67	5.41	9.02	9.12	8.99	9.43	8.81	8.68

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[a] Concentration in milligrams per liter unless otherwise indicated.

TABLE D-16. ANALYSES OF SCRUBBER LIQUORS FROM APS CHOLLA STATION (FDS AND ABSORPTION TOWER SCRUBBER SYSTEM)

Scrubber liquor constituents[a]	In-process data		Potential discharge data point	
	Sample location			
	Absorption tower tank		FDS tank	
	Sample date			
	4/1/74	11/7/74	4/1/74	11/7/74
Aluminum (Al)	0.06	2.1	2	--
Antimony (Sb)	0.03	0.16	0.09	0.22
Arsenic (As)	<0.004	0.02	<0.004	--
Beryllium (Be)	0.08	<0.003	0.14	0.04
Boron (B)	--	3.8	--	8.0
Cadmium (Cd)	0.007	0.012	0.011	0.044
Calcium (Ca)	580	390	680	770
Chromium (Cr) (total)	0.02	0.004	0.14	0.024
Cobalt (Co)	0.05	<0.01	0.17	0.1
Copper (Cu)	0.03	0.01	0.20	0.16
Iron (Fe)	0.17	0.13	0.42	8.1
Lead (Pb)	0.02	0.15	0.01	0.37
Magnesium (Mg)	7	9	3	4
Manganese (Mn)	0.30	0.48	0.34	2.5
Mercury (Hg)	0.007	<0.5	0.07	<0.05
Molybdenum (Mo)	--	0.09	--	0.91
Nickel (Ni)	1.0	0.06	1.5	0.30
Potassium (K)	--	7.5	16	28
Selenium (Se)	1.0	<0.033	2.2	<0.001
Silicon (Si)	1.7	--	3.3	--
Silver (Ag)	0.01	<0.007	0.03	0.05
Sodium (Na)	800	370	2250	1650
Tin (Sn)	--	--	--	--
Vanadium (V)	--	0.07	--	0.67
Zinc (Zn)	0.02	0.04	0.11	0.47
Total carbonate	<1	<1	<1	<1
Chloride (Cl)	620	760	1700	4200
Fluoride (F)	2.4	1.0	0.7	1.5
Sulfite	1.0	21	0.9	3500
Sulfate	2200	1360	4000	3750
Phosphate	<0.1	<0.1	0.41	<0.5
Total nitrogen	<0.005	<0.005	0.002	<0.005
Chemical oxygen demand	105	90	340	390
Total dissolved solids	4300	3300	8700	14000
Total alkalinity	52	130	--	--
Conductance, mho/cm	0.0053	0.00299	0.0112	0.014
Turbidity, Jackson units	<5	<5	<5	<5
pH	6.59	6.80	3.04	3.38

[a] Concentration in milligrams per liter unless otherwise indicated.

TABLE D-17. ANALYSES OF SCRUBBER LIQUORS FROM DLC PHILLIPS STATION: SINGLE- AND DUAL-STAGE VENTURI SCRUBBER SYSTEMS

Scrubber liquor constituents[a]	In-process data		Potential discharge point data		
	Sample location				
	Scrubber effluent		Clarifier underflow		Pond supernate
	Sample date				
	10/4/73	6/17/74	10/4/73	6/17/74	6/17/74
Aluminum (Al)	--	--	--	--	--
Antimony (Sb)	--	--	--	--	--
Arsenic (As)	0.085	0.06	0.09	<0.004	<0.004
Beryllium (Be)	0.012	0.002	0.012	0.003	0.002
Boron (B)	--	--	--	--	--
Cadmium (Cd)	0.022	0.1	0.023	0.05	--
Calcium (Ca)	1300	660	1400	600	600
Chromium (Cr) (total)	0.037	--	0.040	--	--
Cobalt (Co)	--	--	--	--	--
Copper (Cu)	0.06	--	0.07	--	--
Iron (Fe)	--	--	0.026	--	--
Lead (Pb)	0.08	0.5	0.18	0.04	0.4
Magnesium (Mg)	220	--	410	--	--
Manganese (Mn)	--	--	--	--	--
Mercury (Hg)	0.09	0.0004	0.05	0.0002	0.0004
Molybdenum (Mo)	--	--	--	--	--
Nickel (Ni)	--	--	--	--	--
Potassium (K)	20	10	22	26	22
Selenium (Se)	0.8	0.33	0.8	0.028	0.095
Silicon (Si)	--	--	--	--	--
Silver (Ag)	0.02	--	--	--	--
Sodium (Na)	1680	440	2400	320	344
Tin (Sn)	--	--	--	--	--
Vanadium (V)	--	--	--	--	--
Zinc (Zn)	0.12	--	0.09	--	--
Total carbonate	<1	<1	<1	<1	<1
Chloride (Cl)	1800	540	2700	470	420
Fluoride (F)	4.8	8	2.6	10	7
Sulfite	<1	1.7	<1	20	4.8
Sulfate	4500	2700	6450	2720	1000
Phosphate	<0.05	<0.05	<0.05	<0.05	<0.03
Total nitrogen	<0.005	<0.005	<0.005	<0.005	<0.005
Chemical oxygen demand	--	65	--	60	--
Total dissolved solids	9400	4600	14000	4200	4000
Total alkalinity	61	78	--	--	41
Conductance, mho/cm	0.0063	0.0033	0.01	0.0034	0.0030
Turbidity, Jackson units	< 3	< 3	< 3	< 3	< 3
pH	9.20	8.92	7.11	10.70	10.44

[a] Concentration in milligrams per liter unless otherwise indicated.

TABLE D-18. TRACE METAL ANALYSIS OF SCRUBBER SOLIDS FROM TVA SHAWNEE STEAM PLANT

Date: 1 Feb 1973

Conc: ppm

TCA Scrubber-Limestone System

Scrubber Solids Constituents	Sample Description						
	Coal	Limestone	Fly Ash (In)	Fly Ash (Out)	Bottom Ash	Scrubber Effluent	Clarifier Effluent
Arsenic	4	6	32	50	7	52	33
Beryllium	0.2	6	34	0.2	30	0.2	6
Cadmium	1	0.12	0.42	-	0.4	3	1
Chromium	20	10	230	440	700	15	66
Copper	8	4	25	110	220	9	9
Lead	30	0.1	3	7	1	2	1
Mercury	0.6	-	3	7	0.4	1.2	1
Selenium	3	1	8	2	16	11	2
Zinc	180	-	290	1600	-	-	110

TABLE D-19. TRACE METAL ANALYSIS OF SCRUBBER SOLIDS FROM TVA SHAWNEE STEAM PLANT

Date: 12 Jul 1973
Conc: ppm

TCA Scrubber-Limestone System

Scrubber Solids Constituents	Sample Description					
	Coal	Limestone	Fly Ash (In)	Bottom Ash	Scrubber Effluent	Clarifier Effluent
Arsenic	19	7	12	6	7	-
Beryllium	0.2	3	34	33	0.2	0.3
Cadmium	5	0.6	4	0.4	2.5	3.2
Chromium	10	9	9	17	180	250
Copper	8	2	7	9	20	18
Lead	34	1.5	4	1	27	21
Mercury	0.5	1	3	0.1	0.4	1
Selenium	6	2	7	7	12	5
Zinc	220	-	600	-	-	430

TABLE D-20. TRACE METAL ANALYSIS OF SCRUBBER SOLIDS FROM TVA SHAWNEE STEAM PLANT

Date: 27 Nov 1973
Conc: ppm

TCA Scrubber-Limestone System

Scrubber Solids Constituents	Sample Description						
	Coal	Limestone	Fly Ash (In)	Fly Ash (Out)	Bottom Ash	Scrubber Effluent	Clarifier Effluent
Arsenic	12	1	18	-	-	3	30
Beryllium	0.6	0.5	3	1	3	5	3
Cadmium	1	0.5	2	6	0.3	3	0.7
Chromium	18	0	17	23	13	140	100
Copper	15	4	11	2	17	11	8
Lead	27	2	3	6	4	2	2
Mercury	-	-	-	-	-	-	-
Selenium	4	3	2	-	2	5	7
Zinc	100	200	140	230	130	180	160

TABLE D-21. TRACE METAL ANALYSIS OF SCRUBBER SOLIDS FROM TVA SHAWNEE STEAM PLANT

Date: 15 June 1974

TCA Scrubber-Limestone System

Scrubber Solids Constituents	Sample Description	
	Coal	
Arsenic	16	
Beryllium	0.8	
Cadmium	0.5	
Chromium	12	
Copper	9	
Lead	17	
Mercury	0.07	
Selenium	3	
Zinc	60	

TABLE D-22. TRACE METAL ANALYSIS OF SCRUBBER SOLIDS FROM SCE MOHAVE GENERATING STATION

Date: 30 Mar 1973

Conc: ppm

TCA Scrubber-Limestone System

Scrubber Solids Constituents	Sample Description			
	Coal	Fly Ash	Scrubber Effluent	Centrifuge Effluent (Centrate)
Arsenic	3	9	0.8	0.6
Beryllium	<0.1	2	0.06	0.05
Cadmium	0.6	<0.5	0.5	0.5
Chromium	45	105	9	10
Copper	50	50	8	9
Lead	4	25	0.25	0.23
Mercury	0.05	0.05	0.005	0.001
Selenium	1.5	10	5	8
Zinc	10	50	40	45

TABLE D-23. TRACE METAL ANALYSIS OF SCRUBBER SOLIDS FROM TVA SHAWNEE STEAM PLANT

Date: 19 Mar 1974
Conc: ppm

Venturi-Spray Tower-Lime Process

Scrubber Solids Constituents	Sample Description					
	Coal	Fly Ash (In)	Bottom Ash	Scrubber Effluent	Clarifier Effluent	Filter Cake
Arsenic	10	75	5	13	18	13
Beryllium	2	12	3	8	8	11
Cadmium	10	40	1	20	15	4
Chromium	7	50	6	25	20	15
Copper	12	80	16	35	28	30
Lead	40	60	5	25	25	15
Mercury	0.5	0.4	0.6	0.2	0.1	0.2
Selenium	3.4	4	0.7	6.5	7.2	7.8
Zinc	280	350	90	130	280	200

TABLE D-24. TRACE METAL ANALYSIS OF SCRUBBER SOLIDS FROM APS CHOLLA POWER PLANT

Date: 1 April 1974

Conc: ppm

Venturi-Absorption Tower-Limestone System

Scrubber Solids Constituents	Sample Description				
	Coal	Limestone	Fly Ash	Slurry Tank Effluent	Absorption Tower Effluent
Arsenic	2.1	<0.1	0.4	2	0.8
Beryllium	0.5	-	2	1	0.2
Cadmium	0.1	0.01	0.03	0.08	0.06
Chromium	12	11	160	52	48
Copper	39	2	31	76	6
Lead	60	0.5	165	80	14
Mercury	0.05	-	-	4	5
Selenium	5	2	5	17	2
Zinc	55	-	150	120	60

TABLE D-25. TRACE METAL ANALYSIS OF SCRUBBER SOLIDS FROM DLC PHILLIPS STATION

Date: 4 Oct 1973

Conc: ppm

Venturi-Lime System

Scrubber Solids Constituents	Sample Description		
	Coal	Lime	
Arsenic	16	<2	
Beryllium	0.4	0.02	
Cadmium	4	0.03	
Chromium	60	6	
Copper	30	3	
Lead	45	0.1	
Mercury	-	-	
Selenium	8	22	
Zinc	80	300	

TABLE D-26. TRACE METAL ANALYSIS OF SCRUBBER SOLIDS FROM DLC PHILLIPS STATION

Date: 17 June 1974
conc: ppm

Venturi-Lime System

Scrubber Solids Constituents	Sample Description	
	Coal	
Arsenic	6	
Beryllium	0.8	
Cadmium	0.5	
Chromium	12	
Copper	11	
Lead	12	
Mercury	-	
Selenium	3	
Zinc	30	

TABLE D-27. TRACE METAL ANALYSIS OF SCRUBBER SOLIDS FROM GE INDUSTRIAL BOILER

Date: 18 Jul 1974

Conc: ppm

Bubble Cap Scrubber-Double Alkali System

Scrubber Solids Constituents	Sample Description	
	Coal	
Arsenic	14	
Beryllium	1	
Cadmium	0.4	
Chromium	7	
Copper	10	
Lead	16	
Mercury	0.4	
Selenium	6	
Zinc	27	